SCOR Working Group Proposal

Title: **Atmosphere-waves-current interactions and oceanic extremes**

Acronym: **EXTREMES**

Abstract

Both observations and climate predictions anticipate that, although possibly decreasing in the mean, atmospheric and oceanic extreme events will move towards a substantial intensification. This change is connected to the greater amount of energy (increased temperature and humidity) contained in the atmosphere with climate change. A proper analysis of the extreme events and their future development and impacts can only be done employing fully coupled atmosphere-wave-ocean models, as the research of the last ten years has clearly demonstrated. While in recent years remarkable progress has been achieved on modeling capabilities, many crucial aspects of coupling are still to be explored and defined, both in terms of physics and more so as implementation in operational models (Cavaleri et al. 2007). In this SCOR Working Group we plan to bring together some of the leading experts in this field to frame and clarify some of the critical aspects still limiting the accuracy of the present analyses and forecasts. The problem has many facets. We will focus mainly in two directions: “freak waves” in the ocean and in shallow coastal waters, and a deeper coupling between atmospheric and oceanic models towards a better operational system for: a) understanding and forecasting the conditions for the possible appearance of freak waves, and b) a fully coupled coastal system providing improved forecasts of the coastal extremes (especially under storm and surge flooding conditions). At the same time, we will monitor the present trends derived from satellite data using the data available in the next four years.

Scientific Background and Rational

Atmospheric and oceanic modeling have been separated for a long while. Starting from the research and operational models of the 1960s, for about three decades, using the words of Erik Mollo-Christensen, “meteorologists considered the ocean as a wet surface, oceanographers considered the atmosphere as a place where wind blows”. It was only at the end of the 1980s and early 1990s that cooperative efforts between oceanographers and meteorologists led to the realization that interactions at the sea surface are much more complex than previously supposed. It was obvious that a tight coupling between atmospheric and wave models would lead to better predictions of the immediate future for both types of models. However, the ocean was, and partly still is, mostly used in climatic terms as only a boundary condition to the atmosphere.

Today, more than ever, a tight coupling between atmospheric, global circulation and wave models is needed. This is due to various aspects, including the growing concern about climate change and the consequent need of secular projections; the evidence from long-term measured time series of a growing level of the extreme conditions; the longer term projections of the operational meteorological systems (towards seasonal forecasts); the increased vulnerability of the coasts, and the more intensive use of the ocean (ship traffic and oil rigs are obvious examples). All these aspects demonstrate the need for a better fundamental understanding of the first principles governing the coupling between the ocean and atmosphere. This understanding should then be followed by an advanced operational forecast of atmospheric and oceanic conditions for the short term, as well as for climate projections.

Wind waves and the flow of water and air by their moving surfaces are appearing more and more as a key element for all the above-mentioned targets. This comes in view of the fact that sea surface conditions control, within orders of magnitudes, the intensity and the integrated amount of all the exchanges (energy, momentum, heat, gas, solid particles, water, aerosol, etc.) between the atmosphere and ocean. Hence, wind waves are a crucial component in that they determine the physics and, via their modeling, our capability to provide medium-term forecasts, as well as climatic projections.

Among the advancements in atmospheric and oceanic prediction, accurate forecasting of extreme weather events is of specific interest due to their great potential to inflict loss of life and property. Unfortunately, the trends derived from recent observations show that there are reasons for concern. A detailed analysis of altimeter data over the last 30 years has shown that there has been a global increase in the magnitudes of the higher values of both wind speeds and resulting wave heights. In particular, it is the extreme events which are increasing most rapidly (Young et al., 2011). A corresponding analysis of hurricanes and typhoons, in the past and in climate projections, shows that the average intensity of tropical cyclones is increasing. It is predicted that by 2100 the mean intensity of tropical cyclones will increase from Category 3 (today) to Category 4 (Mei et al., 2015). A key global problem is the high concentration of human populations near the coast and in low-laying coastal areas (40-50% of the population). It is mandatory to quantify, in a reliable manner, wave energy and forces acting on the coast. As sea level rises and climate change impacts coastal areas and coastal cities (and mega-cities), extreme events will become more common (more surge-driven flooding and thus more urban infrastructure exposed to waves).

The U.S. East, Gulf of Mexico, and north European coasts provide alarming examples for this trend. In the last 10 to 20 years these coasts have been affected by severe storms that caused serious damages in the coastal zones (e.g., Hurricanes Katrina, Ike, and Sandy in the United States). Additionally, different human activities, such as the offshore wind power and oil industries and coastal recreation, necessitate information about the sea state in the coastal ocean with high resolution in space and time. There seems to be a consensus that high-quality predictions of extreme events like storm surge and flooding caused by storms could substantially contribute to avoiding or minimizing human and material damages and losses (see, among others, Brown et al., 2001 and Wolf et al., 2011). Therefore, reliable forecasts and long-term statistics of extremes are of utmost importance for coastal areas. This cannot be achieved by further neglecting wind-wave-current interactions, both in the open and coastal ocean operational forecasting.

A different, but growing aspect of concern are "freak waves", that is, the anomalously large waves that sometimes seem to appear out of nowhere in the ocean and also in coastal zones. While related measurements are unavoidably limited, a deeper knowledge has now been achieved based on the nonlinear processes of wind waves. However, at the same time it is becoming clearer that a proper estimate of the conditions favorable to their appearance can be obtained only with the use of deeply coupled atmospheric-wave-ocean models. The interaction between waves and current is obvious, and its relevance for freak waves has been extensively shown by analyzing cases reported along the Agulhas Current (see Peregrine, 1976; White and Fornberg, 1998; Lavrenov and Porubov, 2006; and Toffoli et al., 2015). However, the other classical area for these events, the North Sea, has no such strong current, and here freak waves seem to be related uniquely to the nonlinearity of wave processes, once the combined atmosphere-wave action has created the conditions suitable for the events.

On the whole, there is a strong need for a deeper, more detailed coupling, in terms of the physics, between the atmospheric, wave and ocean models and in monitoring the global trends in surface winds and wave conditions (see Toffoli et al., 2005, for the warning criteria for ships). The need for this is clearly reflected in past and present SCOR Groups, from WG 83 "Wave Modeling", WG 101 "Influence of Sea State on the Atmospheric Drag Coefficient", WG103 "The Role of Wave Breaking on Upper Ocean Dynamics", WG 110 "Intercomparison and Validation of Ocean-Atmosphere Flux Fields", WG 111 "Coupling Waves, Currents and Winds in Coastal Models to the present WG141 "Sea-Surface Microlayers" and WG 143 "Dissolved N2O and CH4 Measurements". Especially the two last groups cannot really sort out the proposed problems if the crucial effects on wind and wave interactions are not considered. Indeed, there seems to be a lack of a solid approach towards a better definition of the physical processes at the interface, of the reciprocal interactions between the actors at play, that is, wind, waves and currents, and of the derived role for both the problems cited above and the ones dealt with in the present SCOR working groups.

Terms of References

The problem is multi-faceted and it would be absurd to suggest a full solution in the next four years. We plan to focus on the presently most urgent and crucial aspects. The main points of our actions will be

1. Develop a more refined physical description of the interaction between waves and

ocean currents to quantify their reciprocal influence. Currents affect waves and waves affect currents. This description will be published in a peer-reviewed journal.

2. Develop observational and theoretical approaches to describe the presence of vertically sheared currents and their influence on the characteristics with which waves and their energy propagate on the ocean. Vertically sheared currents are not presently considered aspect in observations and theory. The related description will be published in a peer-reviewed journal
3. Develop coupled atmospheric-waves-current-surge models suitable for coastal zones. The models will be made openly available.
4. Improve the understanding of the physics of freak waves, i.e of wave of anomalous height believed to be the reason of many ship losses.
5. Verify this physics hindcasting (i.e., re-evaluating a posteriori) the storms of historical large freak events and verify that indeed we would have been able to forecast the conditions suitable for a freak event. All these findings (ToR 4 and 5) will be published in peer reviewed journals
6. Update the altimeter database of wind and waves over the oceans providing to the world community a cross-validated highly verified dataset, with also estimates of long term climate trends in wind and waves. Results to be published in peer reviewed journals.

Working plan

The Group will act according to the field of expertise of each person, but with a strong continuous interaction to obtain, along the way and at the end, a set of self-consistent and self-supporting results. The necessary expertise is suitably distributed throughout the Group and the proposed Working Group Members have a long history of cooperation in scientific and operational activities.

In the following description of the Working Plan we refer to the ToR (Terms of Reference) above and the names of the different Members listed in Table 1 shown later. The Working Plan is distributed over 4 years. For each Year and ToR the participants are listed in the order of the Members list.

<u>Year 1</u>

ToR1 – refinements for wave and current interactions (Fan, Qiao, Breivik, Smith, Bidlot),

ToR2 – development of theory (Toledo),

ToR3 – definition of new physics in the atmosphere-wave-current interactions. Special reference is done to the action of rain and on its implications for the physics of wind wave generation and dissipation. (Cavaleri, Fan, Breivik, Bidlot),

ToR4 – development of theory, experimental work using optical approach with focus on both open ocean and coastal shallow waters (Onorato),

ToR5 – collection of data of the main documented freak wave historical events (Cavaleri, Breivik, Bidlot, Onorato),
ToR6 – collection of data (Cavaleri, Young, Bidlot)

<u>Year 2</u>
ToR1 – implementation of theory into operational models – application to the Gulf of Mexico, North Sea, and Mediterranean Sea (Fan, Qiao, Breivik, Smith, Bidlot),
ToR2 – development of theory and laboratory experiments – report of results (Breivik, Toledo),
ToR3 – implementation of the new physics into the coupled modeling system in the North Atlantic Ocean and the Mediterranean Sea – results of the experiments (Cavaleri, Fan, Qiao, Breivik, Smith, Ocampo-Torres, Bidlot),
ToR4 – validation of the theoretical approach – paper (Cavaleri, Onorato),
ToR5 – application of the coupled system to the hindcast of the storms in connection with the selected freak events – results of the experiments (Cavaleri, Breivik, Bidlot, Onorato, Monbaliu),
ToR6 – collection of data – statistics of the trends (Cavaleri, Young, Bidlot)

<u>Year 3</u>
ToR1 – hindcast of selected storms in the Gulf of Mexico, North Sea and Mediterranean Sea (Fan, Breivik, Staneva, Smith, Bidlot),
ToR2 – validation of theory - paper (Breivik, Toledo),
ToR3 – intercomparison of the results obtained with the previous approach and the one derived from the new physics - papers (Cavaleri, Fan, Qiao, Breivik, Staneva, Smith, Ocampo-Torres, Bidlot, Monbaliu),
ToR4 – further testing of theory and possible further theoretical developments – paper (Cavaleri, Onorato),
ToR5 – use of the hindcast results for freak wave simulation and check of the related probability - paper (Cavaleri, Breivik, Bidlot, Onorato, Monbaliu),
ToR6 – collection of data – update of the database and of the trends – paper (Cavaleri, Young, Bidlot)

<u>Year 4</u>
ToR1 –intercomparison of the results obtained with the previous and new coupling – paper – results and theory available (Fan, Qiao, Breivik, Staneva, Smith, Bidlot),
ToR2 – final framing of the basic results – paper – theory and method available (Breivik, Toledo),
ToR3 – examples and results available – papers (Cavaleri, Fan, Breivik, Staneva, Smith, Ocampo-Torres, Bidlot, Monbaliu),
ToR4 – final framing of the basic results – paper – theory and method available (Cavaleri, Onorato),
ToR5 – final framing of the basic results – paper – theory and method available (Cavaleri, Breivik, Bidlot, Onorato),
ToR6 – collection of data – new database and possible trends available – paper (Cavaleri, Young, Bidlot)

Deliverables

The list of Deliverable is strictly connected to the above Terms of References

D1 (ToF 1) – A more advanced physics of the interaction between waves and current, in particular for what concerns the evaluation and the effects of Stokes drift and Coriolis effects – one or two papers will be produced.
D2 (ToF 2) – Experimental results on the effect of a vertically sheared current on the propagation of surface waves – development of the related theory – two papers will be produced.
D3 (ToF 3) – A coupled atmosphere-waves-current-surge model – examples of its application to the North Sea – two papers will be produced – when available and verified the model will be available to the scientific community.
D4 (ToF 4) – Improved theory of freak waves and two papers.
D5 (ToF 5) – Meteorological and oceanographic reconstruction (hindcast) of at least two historical storms during which exceptionally high freak waves have been measured - application of the theory developed at ToF 4 – verification of the capability of forecasting, in operational conditions, the possibility and the probability of freak waves – two papers.
D6 (ToF 6) – Cross-validated and verified long-term data base of altimeter wind and waves on the whole world with estimate and updating of the climate trends – one paper.

Capacity Building

The final and lasting results of the four-year activity of the EXTREMES SCOR working group are represented by the (final) results listed in the above Working Plan and Deliverables. These can be summarized in the following basic, but very important, points:

1. We will provide the basis for a more detailed theory of the interactions between waves and currents with the possibility of better forecasts of the meteorological and oceanographic conditions on the ocean and in coastal areas.
2. The application of these results to the operational models will produce better forecasts, in particular in coastal areas, with a better anticipation, as quality and forecast time, of potential floods, hence earlier warnings to the population. The model will be applied, among others, by FIO (China) and CICESE (Mexico) (see the Full Members list) to improve the local modelling, particularly in extreme (hurricane and typhoon) conditions..
3. One of the Members meeting, during the third year of the project, will be held in China (FIO, see Full Members list), combining it with the periodic oceanographic and climate course there held. In this way the many attending students from developing countries will be able to take advantage of the new findings.
4. There will be a better understanding of the physics of freak waves and of the conditions under which their appearance may become more likely. There will be a better capability of issuing warning to ships and open sea oil platforms of the possibility of anomalously large waves in an incoming storm, particularly during hurricane and typhoon conditions,

respectively in the Gulf of Mexico and Caribbean Sea, and in the South China Sea respectively..

Working Group composition

We have included in the proposed Group major experts and active players in the discipline of atmosphere-wave-ocean coupled systems, satellite data and their use for long-term analysis, and freak waves. The geographical distribution is spread throughout four continents (Italy, Belgium, China, Norway, Germany, Israel, Great Britain, USA, Mexico, and Australia). No scientific discipline is associated to a single Member, but we have carefully distributed the tasks and responsibility reflecting the competence in also the different countries. Attention has been given to the gender distribution that reflects, with increased female participation, the distribution of the researchers and experts in the considered field. Two valuable scientists from transition economy countries (Mexico and China) will contribute to the final results.

Table 1 – Full Members

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
1 – Luigi Cavaleri Chair	M	ISMAR, Venice, Italy	wave modeling, coupled system, hindcast, measured data
2 – Yalin Fan Vice-chair	F	U.S. Naval Research Laboratory, Stennis Space Center, MS, USA	air-sea interactions and their effects in coupled models
3 – Fangli Qiao	M	First Institute of Oceanography, Qingdao, P.R China	non-breaking waves induced mixing and their influence in circulation and climate models
4 - Oyvind Breivik	M	Norwegian Meteorological Institute, Bergen, Norway	fully coupled atm-wave-cur systems
5 – Johanna Staneva	F	Institute for Coastal Research, HZG, Germany	coupled wave-current system in coastal waters, forecast systems
6 – Yaron Toledo	M	Tel-Aviv Univ., Tel Aviv, Israel	basic wave theory, nonlinear processes in wind waves
7 – Jane Smith	F	US Army Eng, Res. Develop. Center, Vicksburg, MS, USA	fully coupled systems and oceanic extremes, physics and applications, non-linear waves

8 – Ian Young	M	Univ. of Melbourne, Vic 3010, Australia	basic physics of wind waves generation and dissipation, long term data sets, long term climatology of wind speeds and wave heights on the oceans
9 – Francisco Ocampo-Torres	M	Dpt.Phys.Oceanogr., CICESE, Ensenada, Mexico	physics of wind waves, waves-current interactions, generation and dissipation of wind waves
10 – Jean-Raymond Bidlot	M	Research Dpt, ECMWF, Reading, U.K.	operational global and coupled models, physics of atmosphere-wave –current interaction, long term use of satellite data

Table 2 – Associate Members

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
11 – Miguel Onorato	M	Univ. Torino, Turin, Italy	freak waves, non-linear processes in waves
12 – Jaak Monbaliu	M	Univ. of Leuven, Leuven, Belgium	coastal wave modeling, freak waves in coastal waters

Working Group contribution

Luigi Cavaleri – strong experience (by direct experience in the field and with theory) in the physics of wind waves, their generation and dissipation. Long-term experience in wave and coupled modeling.

Yalin Fan – strong theoretical and modeling experience in air-sea interactions (momentum and energy fluxes, Langmuir turbulence) and their effect in coupled models, Wave modeling and LES modeling.
Fangli Qiao – he developed the non-braking surface wave-induced mixing theory and dramatically improved the crucial vertical mixing of ocean general circulation models and climate models.
Oyvind Breivik – attention to both observing and modeling systems. Very strong experience in fully couple systems both in deep and coastal water conditions.
Johanna Staneva – experience of wave modeling, wave-current interactions and coupled systems. Intensive model application in coastal and regional modeling.
Yaron Toledo – extensive experience in the mathematical modeling of nonlinear wave-bottom and wave-current interactions. Strong experience both in physical oceanography and in its practical aspects as marine measurements and laboratory experiments.

Jane Smith – long-term experience on the physics and applications of wind waves. Modeling in both open and coastal shallow water conditions. Solid basis on fully coupled systems and freak waves.

Ian Young – long-term experience in wave modeling, remote sensing, air-sea interactions and the statistics of environmental extremes. Handling and validation of satellite data and development of a related database with related statistical analysis of long-term trends.

Francisco Ocampo-Torres – Interest in the dynamic of ocean surface waves and the related interaction processes, both with the atmosphere and oceanic currents. Interest and expertise in the processes governing the transfers between the ocean and the atmosphere.

Jean-Raymond Bidlot - At the core of the developments of the atmosphere-wave-ocean coupled system of ECMWF. Validation of model performance against in-situ and altimeter data, including freak waves parameters.

Miguel Onorato – long-term experience in the field of freak waves in the ocean. Solid basis on the related theory and also in laboratory experiments for their simulation.

Jaak Monbaliu – long-term experience in wave modeling in coastal waters. Interest in the impact of extreme waves on marine constructions and in the design of offshore structures.

Relationship to other international programs and SCOR Working Groups

All the activities and the expertise gained in the past by the Working Group Members has been obtained via international cooperation, large national and international projects. For instance Oyvind Breivik has been working for some years at the European Centre for Medium-Range Weather Forecasts (ECMWF, Reading, U.K.), cooperating with Jean-Raymond Bidlot and acting on the coupling between wave and ocean models, an activity he is now carrying and applying in his institute in Norway. ECMWF is the most competent operational centre at the global level in coupled atmosphere-wave-ocean modeling. Several of the participants took part to the MyWave EU sponsored project, ended one year ago, with the aim of framing the European wave modeling in the best way to optimize the coupling with ocean models. This activity has a follow up in the present Wave2NEMO project aiming at further improving the coupling, with also a specific attention to the coasts and coupling with storm surge modeling.

As mentioned above at the end of Scientific Background and Rationale, the proposed activity is a natural follow-up in time of some SCOR Working Group of the past, as WG 83 "Wave Modeling", WG 101 "Influence of Sea State on the Atmospheric Drag Coefficient", WG103 "The Role of Wave Breaking on Upper Ocean Dynamics", WG 110 "Intercomparison and Validation of Ocean-Atmosphere Flux Fields", WG 111 "Coupling Waves, Currents and Winds in Coastal Models". Two present WGs that will take advantage of our proposed activities are WG141 "Sea-Surface Microlayers" and WG 143 "Dissolved N2O and CH4 Measurements". These last two subjects, extremely interesting in themselves, may lack the specific know-how we aim to bring into the system concerning the dynamics and the tuning role of the sea surface (under wave conditions) in modulating all the exchanges at the interface. There we believe that our WG will enhance the capability of some of the existing ones. We look forward to active cooperation, as it is necessary between different, but parallel, disciplines to achieve the best overall results.

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Appendix

List of publications for each Full Member

Luigi Cavaleri –

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Luigi Cavaleri

Venice, 06 April, 2016

PROPOSAL FOR IBDIOCC- SCOR WG

Submitted to: Dr. Edward Urban, Executive Secretary, Scientific Committee for Oceanic Research (SCOR)

Submitted by: Dr. Robert Y. George, President, George Institute for Biodiversity and Sustainability (GIBS), 1320 Vanagrif Ct., Wake Forest, North Carolina.

Date of Submission: April 15, 2016.

IBDIOCC

<u>Interaction Between Drivers Impacting Ocean Carbonate Chemistry:</u> How can Deep-Sea Coral Ecosystems respond to ASH/CSH Shoaling in Seamounts that pose imminent threats from Ocean Acidification?

Summary/Abstract:

We propose a new SCOR Working Group IBDIOCC (2017 to 2019) that seeks to assess new impacts on seamount ecosystems from ocean acidification (OA), that essentially looks at the impact of shoaling of ASH and CSH on the biota that include communities/species associated with deep sea scleractinian corals e.g. *Lophelia pertusa* and *Solenosmilia variabilis*) The WG, with members from both southern and northern hemispheres, seeks to re-evaluate and augment the science priorities defined in 2012 by the Census of the Marine Life, but taking into account the new climate change threats and challenges from shifts in ocean carbonate chemistry. The WG will incorporate recommendations from ‘Ocean In High Carbon World-Ocean Acidification international symposium which will be participated by Dr. George (chairman of WG) who will also present a paper on vulnerable deep sea ecosystems to ocean carbonate chemistry, especially seamounts southeast of Australia and New Zealand. The WG plans to develop a follow-on capacity building workshop in the ASLO annual meeting in Hawaii (2017) and in the AGU Ocean Sciences meeting in Portland, Oregon (2018). In 2017, the WG will meet for three days in 2017 at the ASLO annual meeting to generate two open-access publications; 1) the first global assessment of OA on seamount fauna, and 2) a peer-reviewed multi-authored paper to be submitted to *NATURE* CLIMATE. In 2018, the WG will meet for 3 days at Portland Oregon AGU Ocean Sciences meeting. IBDIOCC SCOR WG will focus on synergism between (1) temperature and carbonate saturation; (2) Deoxygenation processes in upwelling areas with seamounts and carbonate saturation; (3) multiple-stress impacts (temperature, deoxygenation and carbonate saturation).
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Scientific Background and Rationale

Deep-Sea Overview:

The biodiversity and ecosystem functioning can change quickly and significantly because of direct (e.g. bottom trawling, deep-water oil spills) and indirect (e.g. climate variation) human impacts (Smith et al, 2009). In addition, two new pressures have been recognized in recent years; 1) ocean acidification, including the effects of changing pH on shell-bearing planktonic and benthic organisms, and 2) In upwelling zones, there is some evidence that OA impact may couple with deoxygenation stress. How deep-sea ecosystems will respond to these new pressures is not clear. Deep-sea seamounts are considered to be especially vulnerable (Consalvey et al, 2010).

Reum et al (2016) succinctly addressed the complex synergism between carbonate chemistry changes and hypoxia in upwelling ecosystems and concluded: " With the continued collection of high-quality carbonate chemistry measurements and their archival on freely accessible databases, analyses like the one we present for the CCE may yield further insight into the relevance of carbonate chemistry variability to contemporary ecological processes as well as guide OA experimental design in other marine systems.

This proposal is timely owing to the increasing interest of "Oceans in the High Carbon World." The proposed work is truly global in scale encompassing Exclusive Economic Zones (EEZs), Extended Continental Shelves and the High Seas (Areas Beyond National Jurisdiction) in all world oceans. There are as many as 100,000 seamounts at least one kilometer in height. However, of these, less than 200 have been studied in any detail and their biodiversity is still poorly known. Depending on the height of the summit they may have particularly high productivity Seamounts are heterogeneous habitats, often spanning a great depth range (Pitcher et al., 2007; Consalvey et al., 2010; Clark et al., 2010). Deep-sea species of the seamount fauna generally has long generation times and therefore seamount communities are particularly sensitive to disturbance

It is only now with the greater availability of Remotely Operated Vehicles (ROVs) and the rapid development of genetic techniques that many issues relating to seamount ecosystems can be resolved. The lack of comprehensive data has led to generalizations about seamounts as a whole. Very often, however, the generalizations apply only to a subset of seamounts, depending also on the biogeographical province and depth band in which they occur (McCain, 2007; Kvile et al., 2013). A concerted effort on studying seamounts is needed, and possible.

Apart from increasing spread of deoxygenation by creating hypoxic or anoxic zones in ocean areas off river deltas, ocean acidification (OA) threatens ocean health through effects on plankton (e.g. pteropods) and benthic shell-bearing animals (corals and mollusks) which in some cases are deep-water habitat engineers. Increasing CO_2 input is expected to decrease ocean pH by 0.3 to 0.5 by 2100, thus lowering the carbon ion concentration of surface waters. This rapid and dramatic scenario of ocean acidification has the potential to have serious effect on calcification of marine organisms. Since industrialization, there has been a substantial increase in CO_2 flux into the oceans from atmosphere. It is cautioned that by 2100, if this flux is not reduced by shifting gear to renewable energy, irreversible damage may occur to our ecosystems and may diminish ecological services.

Volcanic CO_2 vents can provide useful proxies of future OA conditions allowing studies of species responses and ecosystem interactions across CO_2 gradients. Studies at suitable vents in the Mediterranean Sea and elsewhere show that benthic marine systems respond in consistent ways to locally increased CO_2. At the shelf-edge, the ongoing shoaling of carbonate-corrosive waters (with high CO_2 and low pH) threatens cold-water corals, in particular *Lophelia pertusa,* in the North East Atlantic Ocean.

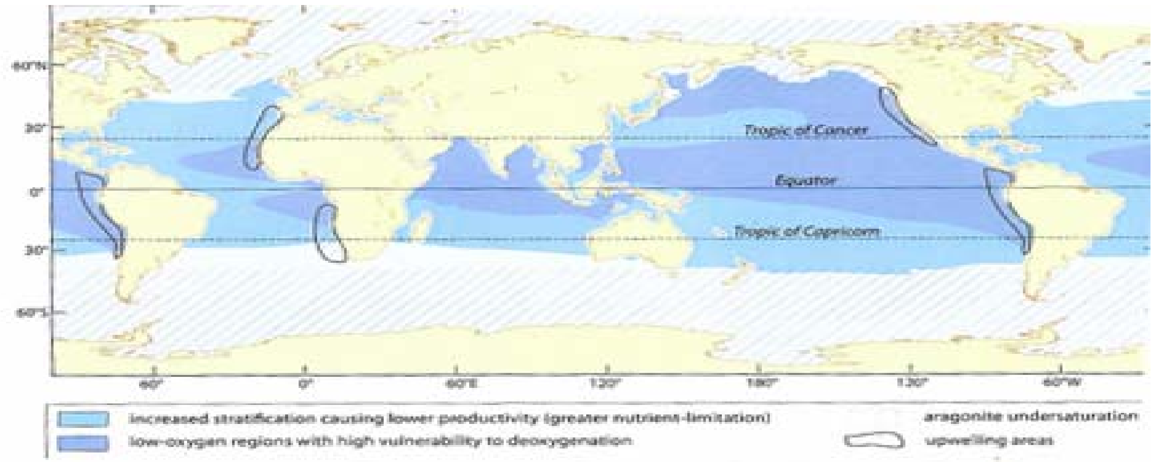
Ocean Acidification in relation to hard corals in the deep-sea

In upwelling areas of the Northeast Pacific Ocean, shoaling of the Aragonite Saturation Horizon (ASH) has reduced hard-coral ecosystems dominated by scleractinian corals. The ASH is located much deeper in the other regions of the deep sea. This led, in part, to Tittensor et al. (2010) postulating that OA threat is really confined to continental margins (continental slopes and plateaus) and that mid-ocean seamounts may not be impacted adversely by OA.

The first consequence of solution of CO2 in seawater is the formation of carbonic acid, but this immediately disassociates to form bicarbonates. To understand the impact on marine skeletal –forming animals, we must look not only at the changing (deceasing) pH, but also at the ambient levels of carbonate saturation of seawater from surface to deep depths. This scenario calls for the need for 'Ocean Observatory" at study-sites offshore, with sensors remotely monitoring and storing information in a database. Decreasing pH may erode skeletal material and calcite under saturation may constrain the rate of production of skeletal material that is aragonite in hard corals and calcite in soft corals

In a recent paper, (Hall-Spencer, 2015) outlined the imminent risks to marine life from ongoing ocean acidification. The increase in carbonate in surface seawater makes it corrosive for animals with aragonite or calcite skeletons such as clams and corals. Decrease in calcification process may make animals to become smaller and smaller, as Hall-Spencer calls it the "Lilliputian effect." In the upwelling zones of the Northeast Pacific ocean, the ASH reaching shallower has over the years reduced or eliminated *Lophelia pertusa et al 2006).* scleractinian *coral species. Guinotte et al, 2006).*

Recently, Gaylord et al., 2015) summarized succinctly ocean acidification through the lens of ecological theory. Likewise, Kroeker et al. (2011) earlier discussed ocean acidification threats with focus on divergent ecosystem responses within benthic marine community. Subsequently, Kroeker et al. (2013) reported that ocean acidification causes ecosystem shifts via altered competitive interactions. Undoubtedly, planetary changes due to ocean acidification have become imminent. The atmospheric methane concentration went up from 1250 to 1750 ppb and atmospheric carbon dioxide went up from 280 to > 400 ppm today and estimated to reach 700 ppm or more by 2100. George (2016) recommends selecting three regions where ocean acidification threats call for careful monitoring with OOI (Ocean Observation Initiatives) that US National Science has recently developed.



Hall-Spencer's Identification of Upwelling Areas in the World Oceans (Circled)

Goals:

1. To determine ocean acidification impacts of pH change on deep-water coral reefs on continental margin and seamount communities above and below the Aragonite Saturation Horizon (ASH) and Calcite Saturation Horizon (CSH).

2. To explain the synergism between deoxygenation and carbonate saturation, synergism between temperature and carbonate saturation and multiple stressor impact involving carbonate saturation and deoxygenation and temperature.

Motivation behind the goals: We submitted a proposal to SCOR for establishing a WG for combing Ocean Acidification (OA) and Cobalt Mining (CM) impacts on seamount communities (deeps-ea corals). We are advised by the reviewers, as per letter from Prof. Peter Burhill (SCOR President), that in a resubmission we should (a) emphasize science *per se* rather than conservation and management of the seamounts and (b) focus on ocean acidification, rather than impacts of cobalt mining on seamount biota.

Work Plan – details of the Terms of Reference (1000 words)

ToR 1. Assess the current status of **threats from ASH shoaling to** *Solenosmilia variabilis* reef in Seamount A 1 off southeast Australia as well as *Lophelia pertusa* reefs on seamounts on both sides of the North Atlantic Ocean.

The WG will focus on knowledge hitherto revealed from published evidence of ASH shoaling on stony corals in seamounts off southeastern Australia, through the efforts of Dr. Ron Thresher of CSIRO, Australia (Thresher et al, 2015). Likewise, the WG will summarize the status of threats to seamount scleractinian corals on both sides of the North Atlantic Ocean.

ToR 2. Raise some questions pertaining to research into natural analogies for ocean change, based on Dr. Hall-Spencer's field experiments at the Mediterranean seep systems, in relation to UN Ocean Acidification officials at IAEA in Monaco and will initiate the first natural High CO2 analogue in the Atlantic.

This effort will test the hypothesis that Atlantic CO2 seeps create gradients in carbonate chemistry that have similar ecological shifts to those noted in the Mediterranean, despite lower alkalinity and a completely different set of species.

ToR. 3. Pool data from Dr. A. Morato's seamount coral data base with 500 seamounts already covered on biodiversity, coral species composition etc. into Dr. George's ongoing work with 'NSF South Big Data Spoke Project' in the Georgia Tech. for developing an interactive website.

Recently a proposal to NSF Directorate of Information and Computer Science is submitted for transferring databases from NSF Ocean Observatory Initiatives (OOI), Ocean Biogeographic Information System (OBIS) and WoRM data pools for various taxonomic groups on biodiversity into Encyclopedia of Life (EoL). The funding for this proposed activity is anticipated in from NSF in August 2016.

ToR 4. Mentor young investigators (postdocs and graduate students) from developing nations in the design process of laboratory and field experimentation to study ocean acidification impact at species to ecosystem levels, involving mesocosm studies.

We intend to develop a summer course in 2018 at the Friday Harbor Laboratories of the University of Washington where there is an ongoing Ocean Acidification Research Facility under the direction of Dr. Billie J. Swalla.

ToR. 5. Identify possible genetic connectivity between seamount fauna with focus on deep sea coral species of the octocoral genera *Narella, Paragorgia, Primnoa* and *Corralium,* based on available knowledge from the work of Dr. Amy Baco-Taylor and her collaborators.

This WG will assemble data from ongoing research in various labratories and numerous published papers on genetic connectivity between seamount fame-work-forming deep-sea corals.

ToR 6. Engage with policy makers (Dr. Mike Orbach) for 'Science-based Management' of Seamount Ecosystems creation of MPAs with potential High Seas seamounts**.**

Dr. George is currently serving as USA delegate to ICES (International Council for the Explorations of Seas) that is currently engaged in designating MPAs in High Seas and within EEZs of different nations in the North Atlantic. Dr. Orbach is associated with the Sargasso Sea Commission. This WG, based on, our efforts in 2017, will recommend vulnerable seamounts as candidates for new MPAs.

ToR. 7. Assess our current knowledge on seamount ecosystems in the Indian Ocean, in the light of ongoing IIOE-2 and the expertise of Dr. Baban Ingole (WG member) and Dr. Banakar (WG Associate member), with specific focus on deep-sea corals and potential ASH (OA) impacts, related to climate change in the Indian Ocean.

This WG will explore the possibility of recommending young investigators to participate in the ongoing IIOE-s cruises to seamounts in the Indian Ocean and will also procure samples of deep sea corals for DNA sequencing in selected genome laboratories where deep sea coral research is now in progress in Australia, New Zealand, Brazil, USA and Europe.

In 2014 the UN Convention on Biological Diversity (CBD), in collaboration with UNEP, updated the impacts of OA in a report on “A Updated Synthesis on the Impacts of Ocean Acidification Impacts on Marine Biodiversity” (Hennige, Roberts and Williamson (2014). Using the information from this paper, this WG will bring together the full members this workshop at the AGU Ocean Sciences conference in Portland, Oregon (2018), and will produce an open access publication on the conservation and management of deep-sea seamounts, including a forward-looking 10-year international research plan.

Deliverables

In addition to the 3 deliverables related to the ToR detailed above, IBDIOCC will prepare a multi-authored comprehensive science paper on potential impact of ocean acidification with emphasis on shell-bearing fauna in the seamounts such as scleractinian coral species. This paper will include the following research questions: (1) How ASH and CSH will behave in different geographic regions, upwelling zones on the eastern parts of world oceans vs. non-upwelling zones on western parts of the world oceans, and (2) Which deep-sea coral species have inherent genetic adaptability to be resilient in low pH conditions (and what shore-based OA study facilities are called for in order to conduct long-term experiments on chosen deep-sea corals.

Capacity Building Plan

Much of capacity building and training in marine science, conservation and management is focused on coastal systems. The marine training portal www.marinetraining.eu, as a measure of international opportunities, shows only a very limited number of courses targeting human impacts and deep-water systems. Searching the keyword “ocean acidification” provides only a negligible number of records. The importance and scale by which OA may impact biodiversity and ecosystem functioning in deep-water have not been reflected in training programs that have been organized to date. This is of concern as developing countries start to utilize offshore resources within their Exclusive Economic Zones (EEZs). Therefore, building knowledge and training capacity on OA in developed and developing countries (e.g. India, Uruguay, Brazil) will be of immense value, by the outcome of efforts from IBDIOCC.

We aim to inform and educate young scientists on the threats, research needs and management tools for the conservation of biodiversity on seamounts. We aim to conduct new capacity building activities related to IBDIOCC.

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This SCOR WG IBDIOCC will conduct a workshop in AGU Ocean Sciences meetings in Portland, Oregon in 2018 and will also participate in the summers of 2017 and 2018 in a graduate course at Friday Harbor Laboratories “Deep-Sea Ecosystems with focus on Seamount Ecology.” This course will educate 20 students each year, on topics of direct importance to the student’s country of origin.

In addition to these initiatives IBDIOCC, we will search for funding from agencies (e.g. NSF and private foundations (e.g. Packard) to provide scholarships for students from developing countries to attend targeted workshops. Already, Dr Bob George serves as senior scientist with Georgia Technical Institute's Dr. Ashok Goel with the NSF South Big Data Hub Spoke Project to pool data of deep-sea coral biodiversity and biogeography into Encyclopedia of Life (EoL). Dr. George will also get data from NSF OOI (Ocean Observatory Initiative) from different observatories.

Relationship to other SCOR WGs and International Programs:

IBDIOCC seeks to interact with the following ongoing efforts that emphasize the need to resolve OA threats to marine ecosystems and biodiversity. Apart from work on seafloor mapping and ocean observatories, SCOR has had little focus on benthic ecosystems in the world's oceans in the past. IBDIOCC builds on interests in SCOR on oceans in a high CO2 world and ocean acidification to fill a important gap in SCOR's past and present work.

International programs that will benefit directly from IBDIOCC and which have produced reports calling for research produced by CCCSOS are:

1. 2014 Recommendations from Convention for Biological Diversity (CBD) Report

2. SCOR WG will interact with Prof. Alex Rogers, Professor of Zoology at Oxford, UK and will use his consultant service on seamount ecosystem research.

3. Dr. Maria Baker of National Oceanography Center and the University of Southampton UK has consented help as liaison between the SCOR WG and INDEEP and DOSI (Deep-Ocean Stewardship Initiatives) that have made significant progress under the leadership of Prof. Lisa Levin of Scripps Institution of Oceanography and Prof. Elva Escobar of UNAM, Mexico to assemble concerned deep-ocean scientists to address issues such as:

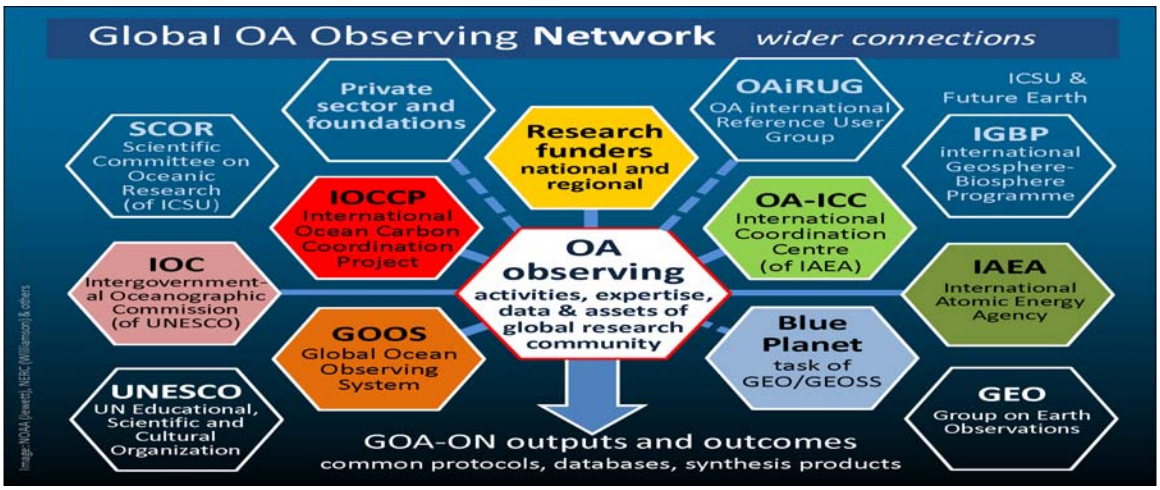
   (A) Global Ocean Assessment (Dr. Tony Koslow, Scripps Institution of Oceanography)
   (B) Ocean Conservation (Dr. Jeff Ardron, Commonwealth Secretariat, London)
   (C) Collaborations with Developing Nations (Dr. Christian Neumann)
   (D) High Sea and Sargasso Sea Commission (Dr. Kristina, Gjerde, IUCN)
   (E) Networking (Dr. Maria Baker, NOC, University of Southampton, UK)
   (F) Deep-Sea Fisheries (Dr. Les Watling, University of Hawaii)

4. The SCOR WG will also interact with Dr. Tim Shank who will host the 2016 Deep-Sea Coral Symposium. Note: the first International deep-sea coral symposium in USA was coordinated by Prof.. Robert Y. George (GIBS) and Dr. Robert Brock (NOAA) at the University of Miami in 2005). Dr. George co-edited this symposium proceedings with Dr. Stephen Cairns of Smithsonian Institution in two volumes, one entitled:"Conservation and Adaptive Management of Deep-Sea coral and seamount ecosystems."

5. The WG will bring together the outcome of the two workshops, one in ASLO meeting in 2017 and the other in AGU Ocean Sciences meeting in Portland, Oregon and will produce an open access publication that entails forward-looking 10-year international seamount research and conservation plan

6. Global Ocean Acidification Network (GOAN)

   We are also aware of the existing "Global Ocean Acidification Network", with a vast number of scientists and managers from many nations, actively involved in OA research and monitoring efforts in the world ocean with Dr. Libby Jewett of NOAA as a coordinator of this activity, as illustrated below. The Scientific Committee for Oceanic Research (SCOR) is one of many participants in this ongoing network



Collaboration with GOA-ON, NOAA AND OA science experts

Dr. Sam Dupont at the Department of Biological and Environmental Sciences of Gothenburg University and Sven Loven Center for Marine Sciences, Kristineberg, Sweden (Vice-Chair of this SCOR IBDIOCC WG) will serve as a liaison with 2016 SCOR WG # 149 that looks multistress impact in marine ecosystems. Dr. Dupont is a member of Executive Council of Global Observatory Network for Ocean Acidification (GOA-ON) and he is leader of the Biology WG of GOA-ON).

Dr. Bob George will also hold IBDIOCC planning meeting in Hobart on May 5 with Dr. Richard A, Feely (NOAA) Dr. Libby Jewett (NOAA), Dr. Phil Boyd in the Institute of Marine and Antarctic Studies Australia (who chair the SCOR WG # 149 that addresses the multiple-stressors and also Dr. Jean-Pierre Gattuso (University of Pierre-et-Marie Curie) who chairs the 'Ocean in the High Carbon World' symposium in Hobart (May 3-6, 2016) and will explore potential avenues for collaborations.

SCOR WG IBDIOCC (Seamounts & Ocean Acidification)

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

Name	Gender	Place of work	Expertise relevant to proposal
1 Prof.Robert Y. George (CHAIR)	Male	GIBS, Raleigh, North Carolina	Deep-Sea Ecology. Ocean Acidification
2 Dr. Sam Dupont (VICE_CHAIR)	Male	Kristineberg, Sweden	Ocean Acidification
3 Dr. Mark Eakin	Male	NOAA, USA	NOAA OA WG
4 Dr. Baban Ingole	Male	NIO, Goa, India	Seamounts Ecology
5 Dr. Marcelo Kitahara	Male	Sao Paulo, Brazil	Deep-Sea Corals
6 Dr. Jason Hall-Spencer	Male	University of Plymouth, UK	High Carbon Oceans
7 Dr. Amy Baco-Taylor	Female	Florida State University	Seamount and deep-sea Corals
8 Dr. Di Tracey	Female	National Institute for Water and Atmospheric Research, New Zealand	Deep-Sea Hard Corals
9 Prof. Alvar Carranza	Male	University of Ghent Belgium	Deep-Sea seeps and nematode biodiversity
10 Dr. Sarma V.B. Yellepeddi	Male	ARAMCO, Saudi Arabia	Deep Sea Explorations and Physical oceanography

Associate Members (no more than 10)

Name	Gender	Place of work	Expertise relevant to proposal
1 Dr. David Billet	Male	NOC, Southampton, UK	Deep-Sea Ecology
2 Dr. Thomas Hourigan	Male	NOAA, USA	Deep-Sea Corals
3 Michael Orbach	Male	Duke University	Marine Policy/Conservation
4 Dr. Telmo Morato	Male	Univ. of Portugal-Azores	Seamount Ecosystems
5 Dr. Debora Pires	Female	National Museum, Rio de Janeiro, Brazil	Deep-Sea Corals
6 Dr. David Eggleston	Male	CMST, NCSU Raleigh, NC	Coastal & Marine Ecology/Food-chain/Ecosystems
7 Dr. Ann Vanreusel	Female	University of Brussels	Capacity Building
8 Dr. Ron Thresher	Male	CSIRO, Hobart, Australia	Seamount Ecology
9 Dr. V. K. Banakar	Male	NIO, GOA, India	Indian Ocean-Seamounts
10 Dr. Karen Stocks	Female	University of California San Diego	Seamount Fisheries

BIODATA OF MEMBERS AND SELECTED PUBLICATIONS

1. **Dr. Robert Y. George (GIBS) – Chair**

Dr. Robert Y. George was Professor of Biological Oceanography for 30 years (1972-2002) at UNC-Wilmington, North Carolina, USA and he taught a graduate course on deep-sea biology. Dr. George conducted original deep-sea research for 40 years off North Carolina Coast, Puerto Rico Trench, Blake Plateau Coral Ecosystems, Sargasso Sea (Beaufort – Bermuda Transect), Arctic and Antarctic deep-sea. Since 2002, Dr. George has been the President and CEO of the George Institute for Biodiversity and Sustainability, a Non-Profit 501-C-3 organization in North Carolina. Dr. George now serves as NOAA delegate to ICES (International Council for Exploration of Seas) Deep-Sea Working Group, since 2005, and also organized with NOAA the 3^{rd} international deep-sea coral symposium at the University of Miami.

2. **Dr. Sam Dupont, Kristineberg Sweden. –Vice-Chair**

Sam Dupont is a Researcher and an Associate Professor in Marine Ecophysiologist at the University of Gothenburg and an Honorary Assistant Professor at the School of Biological Sciences, Hong Kong University. He has published more than 130 publications in journals including Nature, PNAS and TREE. His work aims at revealing the mechanisms behind species and ecosystem responses to environmental changes and at developing the needed unifying theory for large-scale projections. He is in direct contacts with various stakeholders, both at local and global level. He is a member of the Advisory Board of the Ocean Acidification International Coordination Center (OA-ICC), the Executive Council of the Global Ocean Acidification Observing Network (GOA-ON) and the Steering committee of the EuroMarine consortium.

3. **Dr. Mark Eakin (Vice-Chair), NOAA Ocean Acidification Workgroup**

Dr. C. Mark Eakin has worked for the National Oceanic and Atmospheric Administration for over 20 years and directs Coral Reef Watch, a program that monitors coral reef ecosystems through satellite and in water observations. Dr. Eakin holds a Ph.D. from the University of Miami and publishes on coral reef ecology, especially the impact of climate change on coral reefs, coral bleaching, ocean acidification, oil spills, coral paleoclimatology, and the behavior of marine organisms. He co-chaired the US Coral Reef Task Force's Climate Change Working Group, has testified before the US Congress on the impacts of climate change, and was a contributing author on the 2014 Intergovernmental Panel on Climate Change Assessment Report.

. 4. **Dr. Baban Ingole (NIO. Goa, India)**

Dr. Ingole is Professor & Chief Scientist at Goa based National Institute of Oceanography since 1981 and presently leading a research programs on coastal and deep-sea biodiversity & Resource Management. He also participated in Census of Marine Life-CoML, SEATOS- Discovery Channel's International Tsunami Expedition; *INDEEP* international research programs such as: - International Network for Scientific Investigations of Deep-sea Ecosystems; International Seabed Authority's impact of deep sea mining; SCOR special group on Seafloor Ecosystem

Functions and their Role in Global Processes; SCOR visiting scholar.

5. Dr. Marcelo Kitahara (University of Sao Paulo, Brazil)

Dr Kitahara is a deep-sea coral molecular biologist at the University of Sao Paulo, Brazil, using molecular approaches in addition to morphology (micro architecture, and macro and microstructure of the skeleton), fossil data, and bioinformatics to study the evolutionary history of scleractinian corals and related groups, such Corallimorpharia. This research is showing how scleractinians have survived climate change and OA events in the past and shedding light on how corals of ecological and economic importance will cope with increasing modern anthropogenic pressures.

6. Dr. Jason Hall-Spencer (Professor, University of Plymouth, UK)

Jason Hall-Spencer is Professor of Marine Biology at Plymouth University in a city home to >500 marine scientists at the Marine Institute, the Marine Biological Association of the UK, the Sir Alistair Hardy Foundation for Ocean Science and Plymouth Marine Laboratory. He now leads a group of 9 PhD students who conduct applied research to provide policy makers with the scientific information needed to best manage the marine environment, ranging from deep-sea benthos, fisheries, aquaculture, marine protected areas, biogenic reefs and seamounts. His research has attracted grant income from various EU projects (COST IMPACT, MARINEXUS, FP7 KNOWSEAS, FP7 MEDSEA, 3 EU MARES PhD studentships) and from NERC. He has >100 publications.

7. Dr. Amy Baco-Taylor, Florida State University

Baco-Taylor has been studying deep-sea corals on seamounts since 1998 using submersibles, ROVs and AUVs. She has studied these communities throughout the Hawaiian Archipelago and into the broader Pacific including Alaska, Necker Ridge, and New Zealand. Her research on deep-sea corals has included exploration for deep-sea coral and sponge communities, examining the distributions of deep-sea coral species on seamounts, coral reproductive biology, developing and screening microsatellite markers for several species of precious corals and delineating precious coral stock structure through population genetics. She has also been involved in a number of international meta-analyses efforts to determine habitat suitability models for deep-sea corals, and to compare the communities of cobalt-rich vs. non-cobalt rich seamounts. She has current NSF funding to study the recovery of seamount coral communities from trawling impacts.

8. **Dr. Di Tracey (NIWA, NEW ZEALAND**)

Di Tracey is a deep-sea scientist at NIWA in Wellington. She has had a 35-year career researching the biology of deep-sea fishes and invertebrates in specific deep-sea habitats such as seamounts. Her recent work has been on the taxonomy, distribution, and age and growth of protected deep-sea corals. She co-convened the 4th International Symposium on Deep Sea Corals, is a on the 6th International Deep-Sea Coral Symposium Science Steering Committee, and leads the New Zealand- United States Joint Commission Meeting (JCM) on Science and Technology Cooperation Ocean and Marine Theme Project.

9. Dr. Alvar Carranza (Uruguay)

Dr. Carranza serves as full tenured Professor at the Univeridad de la Uruguay. She is also chair of the university's Environmental Science and Management Program. Dr. Carranza is active in outer continental and slope fisheries program of Uruguay.

10 Dr. Sarma V. B. Yellepeddi, (YVB Sarma) King Abdullah University of Science and Technology, Red Sea Research Center, Saudi Arabia

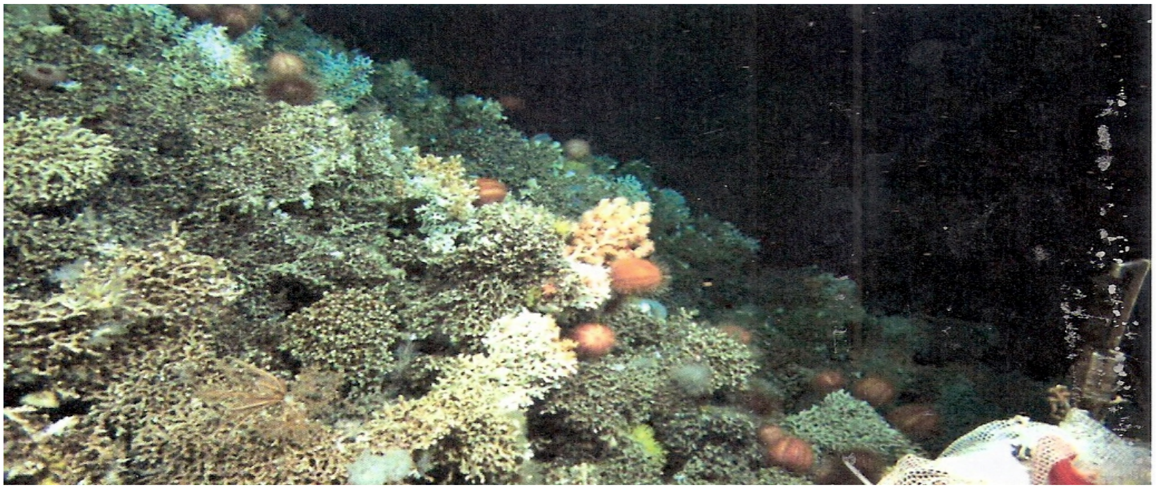
Dr. Sarma is a research scientist working on biophysical and ecological aspects of the Red Sea at King Abdullah University of Science and Technology (KAUST), Saudi Arabia. Earlier he worked as professor at Sultan Qaboos University, Oman. Sarma's work in the recent years is related to changes in thermal characteristics of seas around Oman. Presently establishing ocean observing and prediction system at KAUST that includes, conventional ocean expeditions (for hydrography and ecological studies), automated underwater vehicles (Sea gliders and Webb gliders), Coastal HF radars (CODAR), Towed under water vehicles (Scanfish) and numerical modeling. The acidification is an important factor to investigate in this region as a large coastal fishery depends on the sea for local food security.

Proposed Budget

Total Funds Requested From SCOR: $ 45,000*

*This budget will cover travel cost and hotel/per-diem expenses for (1) WG chair and Vice-chair to hold a Town-Hall meeting on SCOR IBDIOCC goals at the 6th International Deep-Sea Coral Symposium in Boston (Sept. 12-16, 2016): (2) All ten full members of the WG to participate in the workshop at the 2017 ASLO Meeting in Honolulu, Hawaii and 2018 AGU Ocean Sciences meeting in Portland, Oregon (2018). (3) In addition, the budget includes travel cost and per-diem plus hotel expenses for Dr. Robert George, Dr. Mike Orbach, Dr. Sam Dupont, and Dr. Amy Baco-Taylor in Raleigh, North Carolina in 2018 for the preparatory planning meeting for the annual assembly of WG members at Portland Oregon AGU meeting and science paper preparation.

Typical scene of Threatened Deep-Sea Corals From Seamount A off Southeast Australia (See Below):
(Photo Taken at *Solenosimmilia variabilis* Reef at 1300 m (3900 ft) in Seamount system off Southeast Australia By ROV Jason2)



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Appendix

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2. Dr. Sam Dupont, Kristineberg Sweden. (Vice-Chair)

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6.Dr. Jason Hall-Spencer (Professor of Marine Biology, University of Plymouth, UK)

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10 Dr. Sarma V. B. Yellepeddi, (YVB Sarma) King Abdullah University of Science and Technology, Red Sea Research Center, Saudi Arabia

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Biodata of Dr. Michael Orbach, POLICY ADVISOR (Associate Member)

Mike Orbach is Professor Emeritus of Marine Affairs and Policy in the Nicholas School of the Environment at Duke University. Mike has performed research and has been involved in coastal and marine policy on all coasts and oceans of the U.S. and in Mexico, Central and Latin America, the Caribbean, Southeast Asia, Europe, Alaska and the Pacific, and has published widely on social science and policy in coastal and marine environments. He was a formal advisor to both the U.S. Commission on Ocean Policy and the Pew Ocean Commission, and has served on the Ocean Studies Board -- and is a National Associate -- of the National Research Council. He is also a Research Professor in the Institute for Marine Sciences at the University of California at Santa Cruz and an Affiliated Researcher with the Center for Ocean Solutions at Stanford University.

Selected Publication.

Amber Himes-Cornell, Mike Orbach, Lead Authors, Section 4: *Impacts of Climate Change on Human Uses of the Ocean*, *in* Griffis, R. and Howard, J., Eds., 2013. Oceans and Marine Resources in a Changing Climate: A Technical Input to the 2013 National Climate Assessment. Washington, DC: Island Press.

Dr. Thomas Hourigan (NOAA - Science Consultant-Associate Member)

Dr. Hourigan is the Chief Scientist for the National Oceanic and Atmospheric Administration (NOAA) Deep Sea Coral Research and Technology Program, a congressionally-mandated program that provides sound scientific information needed to conserve and manage deep-sea coral ecosystems. Tom also led the team that developed NOAA's *Strategic Plan for Sea Coral and Sponge Ecosystems* and the first report on the *State of Deep Coral Ecosystems of the United States*.

Selected publication:

Hourigan, T.F. (2008). The Status of the Cold-Water Coral Communities of the World: A Brief Update. pp. 57-66 in: C. Wilkinson (ed.), Status of Coral Reefs of the World: 2008. AIMS, Townsville, Australia. 304pp.

Iron Model Intercomparison Project (FeMIP)

Working Group proposal submitted to SCOR April 2016

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SCOR WORKING GROUP PROPOSAL 2016 : FeMIP

1. Summary

The micronutrient iron is at the heart of biological activity in the ocean, shaping marine resources and the global carbon cycle. The iron model intercomparison project (FeMIP) SCOR working group proposes to bring together a diverse set of scientists to deliver new insight into the functioning of the ocean iron cycle, using observations and, in particular, to improve its representation in ocean models. This is important, as the multi-disciplinary work we propose will improve confidence in the projections about how environmental change will affect ocean productivity in iron-limited areas and facilitate the use of numerical models to test hypotheses within a community-driven context of model skill. We aim to produce guidelines for how models can best represent the iron cycle and develop tools for objective interpretations of model skill relative to observations. The impact of underlying inter-model differences in iron cycling will be evaluated and consensus input fields will be produced. Importantly, we will also review how models can take the next important steps and represent the complexity of biological interactions within the iron cycle. A SCOR working group such as proposed here is the only practical means to achieve these important aims.

2. Background and motivation for the working group

2.1 The importance of iron models and their shortcomings

With the recognition that the availability of iron (Fe) plays a central role in shaping biological activity in the ocean [Boyd, et al., 2007; Moore, et al., 2013], most of the numerical models we rely on to test hypotheses and make projections of change now typically represent this resource explicitly. This means that, for example, the projected impact of climate change on biological activity and the carbon cycle in iron-limited regions (e.g. [Bopp, et al., 2013; Cabré, et al., 2014]) can be strongly controlled by how a given model represents the iron cycle [Tagliabue, et al., 2016]. Moreover, due to the central role played by Fe, it is invoked as a potential driver of past changes to the global carbon cycle [Martinez-Garcia, et al., 2014] and as a regulator of both phytoplankton diversity [Ward, et al., 2013] and nitrogen cycling [Monteiro, et al., 2011]. These multi-faceted roles for iron in regulating important components of the coupled ocean-terrestrial-atmosphere system requires that we have good quantitative constraints on its cycling in the ocean, which will raise confidence in the conclusions drawn from numerical models.

Traditionally, numerical model skill is evaluated against global gridded climatologies such as those produced for temperature, salinity, nitrate, phosphate, silicic acid and oxygen by the World Ocean Atlas [Levitus, et al., 2013]. These climatologies can be statistically compared against model outputs to assess model skill and used as initial conditions for model simulations. This process thus provides confidence in the rigour of a given model in reproducing these aspects of the ocean environment. However, despite the importance of Fe to ocean processes, a lack of widespread iron data (in both space and time) has hampered similar efforts to evaluate the skill of iron modelling. Fortunately, there has been a large increase in the availability of Fe measurements over recent years thanks to the GEOTRACES programme [Anderson and Henderson, 2005]. This international effort has begun producing full ocean section distributions for trace elements (including Fe) on a systematic basis and publicly releasing data [Mawji, et al., 2015]. However, the community is still faced with a relatively sparse Fe dataset, relative to those available for the major nutrients. This not only hampers skill assessment, but also in a lack of consensus on appropriate initialisation fields for iron: a crucial component of model results, as seen for the major nutrients.

In response to the greater availability of data, members of this working group initiated a first intercomparison of global iron models with available data [Tagliabue, et al., 2016]. Two important results emerged from this effort: (i) there is a wide variety of residence times for Fe across contemporary models (from 5 to 500 years), with important implications for the sensitivity of the modelled iron cycle to perturbations; and (ii) most models failed to reproduce the broad aspects of the observed Fe distributions, raising concern about the confidence we may have in our iron models and their implications for climate projections. Models that reflected emerging constraints from field observations and process studies often performed better in certain regards, but a given model's complexity was not necessarily the first-order driver of model skill [Tagliabue, et al., 2016].

A stark example of the challenge in modelling Fe comes from the meridional section along the western half of the Atlantic Ocean basin, where the clear water mass structures evident in the distributions of nitrate and phosphate are absent in the iron distribution [Rijkenberg, et al., 2014]. This highlights the unique nature of the ocean iron cycle. Allied to this, the sparse nature of iron data requires us to develop suitable skill metrics to evaluate attempts to represent the unique features of the iron cycle in models.

2.2 The Challenge

Ultimately, improving the modelling of the ocean iron cycle will come from a better understanding of the key processes from both modelling and observations. Broad conceptual understanding is emerging regarding the importance of certain sources and the key facets of the internal cycling of iron, but we lack the quantitative insight that will yield suitable model parameterisations. For example, despite being represented as a key Fe source to the ocean since the very first models [Archer and Johnson, 2000; Parekh, et al., 2005], the amount of Fe supplied by dust deposition still varies widely among contemporary models [Tagliabue, et al., 2016]. In recent years, hydrothermal sources have been recognised as a potentially important Fe source [Klunder, et al., 2011; Nishioka, et al., 2013; Resing, et al., 2015], but are only included in two current global iron models [Tagliabue, et al., 2016]. Equally, evidence for unique aspects to Fe biological cycling and interior ocean regeneration is accumulating [Boyd, et al., 2015; Strzepek, et al., 2012; Tagliabue, et al., 2014; Twining and Baines, 2013; Twining, et al., 2014], but many models still represent these processes very simply, with close coupling to phosphorus cycling. The goal of the FeMIP working group is to assemble an iron model intercomparison project, cutting across different modelling and working closely with observational communities, to address these key challenges. The goal of FeMIP rests on the nexus between observational and modelling science and is three-fold:

- (i) to provide our best understanding of how Fe should be represented in global climate models and to develop tools for consistent evaluation of model skill
- (ii) to deliver the necessary combination of observation and theoretical insight to parameterise the key processes regulating internal Fe cycling
- (iii) to appraise the state of the art and key outstanding gaps in our understanding in the impact of Fe on biological processes.

2.3 Why a SCOR Working Group

We have already shown willingness in the community to conduct this work via our initial intercomparison effort [Tagliabue, et al., 2016]. However to achieve further progress, there needs to be a concerted effort for dialogue between the relevant communities to help improve iron modelling. These communities are diverse and include the modellers themselves, those taking the iron observations (e.g. GEOTRACES), iron chemistry experts, experts in phytoplankton physiology and those investigating iron sources (e.g. atmospheric chemists). This FeMIP working group will assemble this diverse set of scientists to work jointly towards delivering a set of clear objectives that will have wide impact and resonance across the larger ocean and climate scientific communities, ranging from global coupled climate modellers, paleoclimatologists, and IPCC experts to microbial biologists and chemists. The multi-disciplinary and international work we propose would be impossible to support in any other way (e.g. from national or European funding).

3. Terms of reference

(Objective 1, O1) To identify best practices for minimum complexity representations of the iron cycle in models, with options given for more advanced aspects, and publish the guidance in a peer-reviewed paper.

(Objective 2, O2) To develop tools for a wide variety of platforms to validate global model results in a standardised way and make these available via a peer-reviewed publication and a website.

(Objective 3, O3) To facilitate a focussed intercomparison of iron models to constrain the impact of varying residence times and a consensus dust deposition scheme and publish the results in a peer-reviewed journal.

(Objective 4, O4) To review how to represent biological interactions in the iron cycle, the linkages to key phytoplankton species and the interactions with zooplankton and bacteria, as well as broader connections with other biogeochemical cycles and publish the results in a peer-reviewed journal.

4. Work Plan

To deliver O1 we will initially review (using expertise from the working group) the state of the different levels of ocean iron cycle complexity from current models. In parallel, we will assess the key aspects of iron cycling that are crucial for global climate models. This step will be expedited by dialogue between modellers and observationalists on the working group. We will then determine the minimum number of iron pools and the underlying processes to be included in global models. Finally, we will produce governing equations in a unified mathematic notation and default parameter values necessary for parameterisation and test these across a subset of models (e.g. using a relatively simple iron model and one of the most complex models as end members). As part of this effort, we will produce consensus initialisation fields that can be used by the global ocean modelling community. At this point, we will write a peer-reviewed paper in the open access journal *Geoscientific Model Development* (GMD) describing the theoretical underpinning and practical implementation of our recommended minimum complexity iron scheme and initial conditions. Options for the representation of more advanced processes will be included as optional.

To deliver O2 we will review the main computing platforms (e.g., R, Matlab, Ferret and Python) to perform analyses of model skill and identify a platform leader from amongst the working group membership to lead the development of the skill scripts. We will then agree on a common set of model skill metrics and diagnostic plots required to evaluate model performance, as well as a reference iron database from the observations. Each platform leader will be responsible for writing the code, which will be tested against a common model from the initial FeMIP work. An important part of Objective 2 will be the maintenance of 'consensus values' from users to have a community benchmark for contemporary model skill (mean or median, with associated error). This mirrors the efforts made in the observational community with the "SAFe" [Johnson, et al., 2007] trace metal reference samples. A short tutorial to demonstrate how these tools are used will be produced.

To deliver O3 we will first assign two champions to steer this intercomparison work and identify the participants available to conduct additional model experiments, with the aim to encompass a range of residence times. We will choose a series of reference dust deposition schemes and participants will conduct parallel experiments to assess model sensitivity. Linking to Associate Member expertise on these issues will be crucial. A further set of idealised perturbation experiments across the range of models will assess the impact of different underlying residence times to the biogeochemical response on different space and time scales.

Delivering O4 requires reaching out across the full scope of expertise we have assembled from Full and Associate members. We have a broad suite of observational experts who will review key aspects of the biological cycling of Fe: bioavailability, phytoplankton Fe uptake, different iron requirements among diverse phytoplankton species, zooplankton and bacterial recycling and linkages to other biogeochemical cycles (e.g. carbon cycling, nitrogen fixation, silica cycling, food web structure). In detailed dialogue between modellers, experimentalists and observationlists, we will then identify the key phenomena that need to be represented and review how they may be parameterised in models. This will proceed via simplified model experiments at reduced dimensions (e.g. 1-dimensional models) that will made available to the community for further testing with future observational information and may ultimately be used in global scale models.

We plan to hold four annual working group meetings by stretching the funding available from SCOR and other sources, by meeting in conjunction with other related meetings to minimize airfare costs.

Month 1: Kick off meeting. This will focus on planning, with emphasis on O1 and O2, but with reference to O3 and O4. Key champions will be tasked for O1 and O2 and sub-groups will be assembled. We will assign a writing team for the short *Eos* article (Deliverable 1).

Months 1-12: Work on O1 and O2, submit and publish *Eos* article announcing working group.

Month 12: 2nd working group meeting timed to coincide with Ocean Sciences or similar conference. Results from work on O1 and O2 will be presented and reviewed by the group. Work will begin on planning O3. While it is anticipated that O1 will require feedback and continued work, it is planned that O2 will be completed and we will discuss and decide how to publicise the results. At this meeting we will begin discussing work for O4 via presentations on the current state of the art in ocean models and, importantly, emerging paradigms from observational and experimental studies.

Months 12-24: Continued work on O1 and work on O3. Publicise results of O2 via peer-reviewed paper or website (as decided at 2nd working group meeting).

Month 24: 3rd working group meeting. Finalise results of O1 and decide on dissemination strategy. Further discussion of the key processes needed for O4, emphasising the identification of well described phenomena from observations. Sub-group assembled to lead write up key phenomena for O4.

Months 24-36: Continued work on O3 and work on O4.

Month 36: 4th working group meeting. Presentation of results from O3 and writing of peer-reviewed paper. Review of potential means to represent key phenomena identified for O4 in global ocean models.

Months 36-48: Finalising and submitting peer-reviewed paper for O3. Continued work on O4, finalising and submitting paper.

Month 48: Final symposium – we will seek co-sponsors for this workshop, including GEOTRACES, the Ocean Carbon and Biogeochemistry programme (USA), the marine biogeochemistry forum of the Challenger Society (UK), SOLAS and IMBER, as well as others identified in due course. The aim of the symposium will be to highlight progress made in the linking observational work on the internal cycling of Fe to its representation in models. A key challenge for the symposium will be to consider how to extend theory for Fe to other important micronutrients that are at present ignored by biogeochemical models.

5. Deliverables

(1) Inform the community of this working group via a short article in *Eos* or similar publication.

(2) Produce a website to share and publicise our goals and meetings, as well as the outputs of the working group. Contributes to delivering O2.

(3) A peer-reviewed paper in GMD detailing the equations allowing the minimum level of complexity needed to capture important aspects of the iron cycle in climate models, as well as a consensus initialisation field. Delivers O1.

(4) A set of scripts for common data processing platforms, linked to a reference database that produce standardised metrics for model skill, with consensus values updated and publicised via the website. Delivers O2.

(5) A peer-reviewed paper detailing the results of the intercomparison of different dust deposition schemes and the sensitivity of models with varying residence times to fluctuations in iron supply. Delivers O3.

(6) Presentation of the O1, O2 and O3 at international ocean sciences meetings to publicise the findings and stimulate uptake and discussion. Delivers O1-3.

(7) A review article, aimed at *Nature Geoscience* or similar, detailing how to represent important biological linkages in the iron cycle and their connections to wider biogeochemical cycles. Delivers O4.

(8) Organise a co-sponsored symposium to bring observational and modelling scientists together around topic of the review article and towards extending the work done with Fe to other important micronutrients.

6. Capacity building

Numerical models provide an excellent platform for capacity building as many global model codes are open source (e.g. NEMO, MITgcm) and the major barrier to progress is often theoretical understanding rather than expensive equipment. Better dialogue between those taking the iron measurements, conducting experiments on the role of iron in the organism and the modellers is crucially important, but often hampered by lack of common language and forum for the discussions. Moreover, the area of Fe modelling would clearly benefit from a wider user base, applying a suite of theoretical approaches. However, new users are often held back due to the apparent complexity of the ocean Fe cycle. We will provide several practical contributions to aid the uptake and proliferation of biogeochemical modelling. These efforts will link strongly with the activities of the Ocean Model Intercomparison Project as part of the World Climate Research Programme efforts (see Sec 9.2) and will maximise the inclusion of Fe within these 'IPCC-class' models.

Our vision is to open up better dialogue between modellers and observationalists/experimentalists by bringing together these groups in focused forum (this proposed working group). We also envision increasing access to Fe modelling to a wider user base through the activities of this working group. Four practical steps will achieve this. First, the wide distribution of a recommended minimum complexity set of equations and parameters for the modelling of Fe biogeochemistry via Objective 1 will provide a simple means for new users to include Fe cycling in their models to facilitate further development. Moreover, as we will provide options for including more advanced aspects that are linked to working group members there will be clear opportunity for mentorship in further developing understanding. Second, the suite of model skill evaluation scripts and datasets that we will distribute via Objective 2 will facilitate the entry of new ways of modelling Fe cycling by providing a community accepted means of benchmarking model skill. It is anticipated that this will work in a similar way to consensus values for Fe samples that have facilitated new laboratories joining international efforts. We will prepare a short web based video to explain how our model skill scripts should be used. Third, our website and publication efforts will focus effort on understanding the ocean iron cycle, from both modelling and observational standpoints. Finally, we will conduct two training days at the final symposium aimed at training advanced level graduate students that are already working on ocean modelling in use of our recommended iron cycle model and evaluation scripts. Overall, these activities will maximise the building of long lasting global capacity within this important topic.

7. Composition of Working Group

FeMIP has 10 Full and 10 Associate members that bring together state-of-the-art skills in iron cycling modelling, biogeochemical modelling, model skill evaluation and coupled climate modelling, as well as experimental work that will inform on key requirements and future developments. The Full Members are responsible for the delivery of our objectives, while the Associate Members provide important input from the complimentary fields (e.g iron observation, biological cycling, dust deposition) and additional modelling platforms (e.g. intermediate complexity models). Our Full members represent 7 different nations, including 2 emerging/developing nations (South Africa and Turkey). Moreover, we include a number of early career researchers as Full members, which will aid their career development [Urban and Boscolo, 2013].

7.1 Full Members:

Name	Gender	Place of Work	Expertise
Alessandro Tagliabue (co-chair)	M	University of Liverpool United Kingdom	Global iron and biogeochemical modelling
Stephanie Dutkiewicz (co-chair)	F	MIT USA	Ecosystem and biogeochemical modelling
Olivier Aumont	M	IRD/LOCEAN France	Global iron and biogeochemical modelling
Tatiana Ilyina	F	Max Planck Institute for Meteorology Germany	Global biogeochemical and coupled climate modelling
Fanny Monteiro	F	University of Bristol United Kingdom	Modelling links between biogeochemistry, biology and climate
J. Keith Moore	M	UC Irvine USA	Global iron and coupled climate modelling
Yeala Shaked	F	IUI – Eilat Israel	Iron biouptake and bioavailability
Marcello Vichi	M	University of Cape Town South Africa	Global biogeochemical and coupled climate modelling
Christoph Völker	M	Alfred Wegener Institute Germany	Global iron modelling
Mustafa Yücel	M	Middle East Technical University, Turkey	Iron observation

7.2 Associate Members:

Name	Gender	Place of Work	Expertise
Alex Baker	M	University of East Anglia, United Kingdom	Dust supply of iron
Philip Boyd	M	University of Tasmania Australia	Coupled biological and chemical iron cycling
Peter Croot	M	Galway University Ireland	Iron speciation and chemical cycling
Christel Hassler	F	University of Geneva Switzerland	Cycling of iron binding ligands
Jun Nishioka	M	Hokkaido University Japan	Iron distributions in the Pacific and Indian Oceans and colloidal iron cycling

Maite Maldonado	F	University of British Columbia, Canada	Biological iron cycling through the food web
Kazuhiro Misumi	M	CRIEPI Japan	Iron cycling in global models, working on aggregation dynamics
Mark Moore	M	University of Southampton United Kingdom	Biological iron limitation and requirements
Andy Ridgwell	M	UC Riverside USA	Earth system models of intermediate complexity
Benjamin Twining	M	Bigelow USA	Determinations of phytoplankton and zooplankton iron demand

8. Working group contributions

Alessandro Tagliabue is involved in the development of the PISCES model iron component, initiated the FeMIP process and has strong links into the GEOTRACES community via membershop of their steering committee and co-chair of Data Management Committee.

Stephanie Dutkiewicz maintains the biogeochemical – biological component of the MIT DARWIN project model (including iron cycling), with a particular focus on diversity of phytoplankton resource requirements.

Olivier Aumont develops and maintains the iron and ocean biogeochemical components of the PISCES model.

Tatiana Ilyina is a climate modeller (MPI) and represents the needs of this community as end users of the working group's outputs.

Fanny Monteiro is a modeller working on the nexus between biogeochemical cycling, biological activity, and past and future climate (e.g. the role of iron dust deposition on nitrogen cycling).

J. Keith Moore develops and maintains the iron and ocean biogeochemical components of the BEC model, with a particular focus on dust iron input.

Yeala Shaked has a long track record in observing and modelling iron bioavailability and biouptake.

Marcello Vichi develops and maintains the iron and ocean biogeochemical components of the BFM model.

Christoph Völker develops and maintains the iron and ocean biogeochemical components of the RECoM model.

Mustafa Yücel is an expert in the speciation of iron, especially nanoparticulate forms that are thought to dominate supply from dust and hydrothermal vent systems

9. Relationship to other programmes and SCOR working groups

9.1 Other SCOR Working Groups

The activities of SCOR Working Group 139 on organic ligands and in particular the development of ligand datasets and model closures, as well as SCOR/InterRidge Working Group 135 on hydrothermal energy transfer, which provided inputs on hydrothermal iron plumes, will be of benefit to our group (Objective 1). Our working group will interface well with current SCOR Working Group 145 on chemical speciation, with the potential to provide a platform for the wide testing of their chemical speciation models for iron through a range of model platforms. SCOR Working Group 149 is concerned with the responses of ocean biota to environmental change and will ultimately benefit from new models of biological Fe cycling (Objective 4) to assess future projections.

9.2 Ocean Model Intercomparison Project (OMIP) and World Climate Research Programme (WCRP)

The OMIP is an international effort aimed at intercomparing global biogeochemical models that are used in the next IPCC set of simulations as part of the WCRP. We will benefit the activities of OMIP by producing consensus recommendations for model parameterisations, spin up times and initial conditions for Fe (Objective 1). Moreover, our set of skill metrics (Objective 2) will be invaluable of model appraisal. Ultimately, our deliverables as part of Objectives 1 and 2 will facilitate the representation of Fe within a wider set of IPCC global coupled climate models, enhancing confidence in their projections. For example, at present, no consensus exists within OMIP on iron input fields or initial conditions.

9.3 GEOTRACES

Our work is closely linked to that of the GEOTRACES programme. We will make use of their datasets to deliver Objective 2, facilitated by Tagliabue acting as co-chair of their Data Management Committee. Moreover, our activities within Objective 4 will link strongly to ongoing ‘bioGEOTRACES’ efforts. We anticipate GEOTRACES being invited to co-sponsor our final workshop.

9.4 SOLAS and IMBER

Both the SOLAS and IMBER programme will benefit from our work. For example, Objective 3 is aimed at constrained iron deposition from dust, which is a key SOLAS aim. Equally, efforts to improve the representation of Fe cycling by the biological community links strongly to the objectives of the IMBER programme. We anticipate both SOLAS and IMBER being invited to co-sponsor our final workshop.

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SCOR Working Group Proposal on
Measuring Essential Climate Variables in Sea Ice (ECVice)

Summary/Abstract

Observations over recent decades suggest that sea ice plays a significant role in global biogeochemical cycles, providing an active biogeochemical interface at the ocean-atmosphere boundary. However, a pressing need exists to perform methodological intercalibration experiments in sea ice in order to obtain reliable measurements of basic biogeochemical properties [e.g., Arrigo et al., 2010; Miller et al., 2015], including many of the Essential Climate Variables of the Global Climate Observing System. With newly emerging techniques, and pressed by the rapid changes in sea ice, the time has come to evaluate and improve our approach to studying sea-ice systems. An international working group is required to synthesize past intercalibration exercises and to design and coordinate new experiments. Our ultimate goal is to provide the international community with standardized protocols for processing sea-ice samples and collecting data for key variables, including partial pressure of CO_2, nutrients, algal biomass and production, and gas exchange. We will also establish the effectiveness of new techniques to deal with the great heterogeneity (often referred to as “patchiness”) found in sea ice. These tasks will directly serve a long-term community goal of understanding variations in polar marine environments severely affected by ongoing global change.

Scientific Background and Rationale

Sea ice is one of the largest and most dynamic ecosystems on Earth, covering ~10% of the ocean and harboring, in some locations, standing crops similar to productive oceanic regions. In addition to affecting climate through physical processes, sea ice plays a significant but still poorly understood role in the biogeochemical dynamics of the polar oceans [Vancoppenolle et al., 2013]. For example, sea ice contributes up to 60% of the primary production in some parts of the Arctic Ocean [Fernandez-Méndez et al., 2015] and 50% of the CO_2 uptake south of 50°S [Delille et al., 2014]. The algae communities that grow within and on the bottom of sea ice are a fundamental contributor of halogens and aerosols to the polar atmosphere [Abbatt et al., 2012], and the role of sea-ice brine rejection in the global overturning circulation spreads the impact of sea-ice biogeochemical processes throughout the world ocean.

The Global Climate Observing System (GCOS) program has developed a list of essential climate variables (ECVs) and called for systematic observations of these critical variables, in order to support assessment of climate changes. The ECVs have been identified based on relevance for characterizing the climate system and its changes, while maintaining feasibility and cost effectiveness. In the ocean domain the ECVs are: temperature, salinity, sea level, sea state, sea-ice concentration, currents, ocean color, carbon dioxide partial pressure, ocean acidity, nutrients, oxygen, phytoplankton, and tracers. However, GCOS has not been able to provide adequate guidelines for measuring the ECVs in sea ice, a gap this working group will address for a number of variables.

Analyzing biogeochemical properties in sea ice is fundamentally complicated by its inherent heterogeneity and multiphase nature (composed of solid ice, brines, gas bubbles, solid mineral salts, and organic matter), which also introduce difficulties in performing biochemical incubations (which require that the sea ice be homogenized and melted), and thorough evaluations of the various methods used to study sea ice are crucially needed [Miller et al., 2015]. Sea ice is a semisolid matrix permeated by a network of channels and pores, strongly responding to variations in temperature [Golden et al., 2007]. The brine-filled spaces are colonized by sympagic (ice-associated) communities that are both taxonomically diverse and metabolically active [Arrigo et al., 2010], with multiple trophic levels, efficiently consuming, reprocessing, and redistributing chemicals within the ice and exchanging with both the overlying atmosphere and the underlying ocean. Sympagic microbial adaptations involve changes in intracellular processes, but also in extracellular controls, in particular the secretion of extracellular polymeric substances, which modify how the microbial community functions (i.e., by introducing biofilms) and the physical-chemical properties of the ice [Krembs et al., 2011; Ewert and Deming, 2013]. Traditionally, sea-ice ecological studies have been based on methods and concepts from planktonic research. However, in terms of organism distributions, fluid (and nutrient) transport, and predator-prey interactions, the seawater model is less useful than, perhaps, soils or sediments for conceptualizing the sympagic community.

Sea-ice physical, chemical, and biological properties are also extremely variable, both temporally and spatially. Spatial and temporal changes in physical properties are among the largest observed in the oceans, with temperature varying by up to 40 °C over a meter and brine salinity varying by as much as 200 over centimeters. Biomass can vary by an order of magnitude on the sub-meter scale [Eicken et al., 1991], making it difficult to (i) acquire representative measurements or (ii) compare parallel analyses on adjacent cores. In addition, because sea-ice structure is so strongly dependent on temperature, both physical and chemical properties of the ice are easily altered upon sampling or even upon deployment of in-situ sensors (which affect the energy balance).

Numerous approaches have been developed to address these concerns, and there is now a need to rigorously compare them and develop standardized protocols for assessing biological and biogeochemical parameters in sea ice. The following issues are of particularly high priority:

- *Storage of sea-ice samples* can affect measurements in ways that are still difficult to predict. Not only do melting (or even just warming) and refreezing after sampling change the samples, possibly irreversibly (i.e., brine loss, chemical speciation, mineral stability), but bacterial activity has been recorded in intact cores stored in the dark at temperatures below -20°C months after sampling [S. Becquevort, unpublished results]. Instability of the samples affects both biological properties and abiotic compounds.
- *Processing of sea-ice samples* often involves melting them, but many analytes, organisms, and processes are strongly affected by the drastic changes in temperature and salinity that results when sea ice melts [Miller et al., 2015], and quantification of those impacts has been elusive. For example, early studies showed that the drop in salinity with melting can cause losses of 13 to 97% of eukaryotic cells [Garrison and Buck, 1986], but other studies have found no such impact [Rintala et al., 2014].
- *Assessing sea-ice patchiness* and recovering representative data by traditional methods is labour intensive and confined to relatively small areas [e.g., Miller et al., 2015], as well

as largely excluding thicker and highly deformed ice categories [Williams et al., 2015]. New methods using remotely operated vehicles and non-invasive equipment [Külh et al., 2001; Mundy et al., 2007] need to be directly compared with traditional transect and nested sampling techniques.

- *Sea-ice primary production measurements* are scarce, span three orders of magnitude, and have used numerous, distinctively different methods ranging from in-situ sensors to in-vitro isotope labeling studies [e.g., Arrigo et al., 2010; Fernandez-Méndez et al., 2015], for which largely varying results are reported. In addition, preliminary comparisons between incubation protocols (i.e., using melted, crushed, or intact ice sections) for determining metabolic rates in sea-ice communities have identified large differences between treatments [A. Roukaerts, unpublished results]. Additional data need to be collected to evaluate the relative ability of these approaches to estimate sea ice primary productivity.
- *Gas flux measurements over sea ice* using chamber and eddy covariance techniques give results that differ by up to an order of magnitude. In addition to the different spatial scales of the two methods [Nomura et al, 2013], specific technical limitations of both methods impact the measurements [Miller et al., 2015]. These methodological gaps are still not yet fully understood.
- *Measurements of CO_2 partial pressure* in sea ice also use a number of different techniques that give different results [e.g., Miller et al., 2011; Brown et al., 2015], with implications for predictions of carbon release to either the atmosphere or the underlying water. Unlike more inert gases, CO_2 undergoes complex chemistry within ice brines, hydrating to form dissolved carbonate species and precipitating carbonate minerals, and different methods respond differently to that chemistry.

These problems must be solved jointly at the international level, by bringing together sea-ice specialists in these analytical fields to synthesize existing information and determine the best ways to evaluate the differences. Individual, small initiatives are not sufficient to effectively test and evaluate the methods in question, as experts in each of the techniques need to be involved. In addition, the high financial and logistical costs of working in the sea-ice environment requires extensive collaboration. By working together, we will thus be able to deliver to the international community standardized protocols for some of the basic biogeochemical parameters in sea ice.

Terms of Reference

The proposed working group will gather international experts on chemical and biological measurements in sea ice to design and coordinate the required intercomparison and intercalibration experiments. The group will synthesize the results of past experiments, identify what type of new experiments are needed, and support the community in executing those experiments.

- **Publish synthetic reviews compiled from measurements demonstrating large, unresolved discrepancies.** These detailed reviews will draw on both the literature and unpublished studies to evaluate the strengths and weaknesses related to each methodology.

- **Design and coordinate intercalibration experiments to evaluate different methods for key parameters.** In addition to organizing field experiments, we will pursue use of ice tank facilities and stimulate and support applications for funding, at both national and international levels, to further facilite the experiments.
- **Design intercomparison studies to facilitate validation and adoption of new technologies for assessing the complexity and heterogeneity of sea ice at various spatial and temporal scales.**
- **Create a guide of best practices for biological and biogeochemical studies in the sea-ice environment.** This will be accomplished using a web-based forum for compiling and disseminating the outcomes of past and new intercomparison studies.

Working plan

A representative panel of the international community studying sea-ice biogeochemistry will gather at annual meetings to discuss methodological discrepancies, determine priorities for new intercomparison experiments, and develop funding applications. As further detailed below, the primary tasks will be to (i) synthesize available intercalibration experiments, (ii) to design and coordinate intercalibration experiments, and (iii) develop standardized protocols for biogeochemical studies in sea ice. Some of these meetings will be held in conjunction with other conferences, such as the annual meetings of BEPSII (Biogeochemical Exchange Processes at the Sea-Ice Interfaces; a newly designated SOLAS-CliC (Surface Ocean-Lower Atmosphere Study; Climate and Cryosphere)) consortium or sea-ice summer schools.

Task 1: Synthesize current knowledge of discrepancies between methods (years 1-2)

Both published and unpublished studies report large discrepancies between methodologies, especially around protocols for melting ice samples, determining primary production, and measuring gas exchanges. In addition to collating available information from the literature and recent, unpublished experiments, we will attempt to develop mechanistic understandings of the observed discrepancies. The following subjects are our priorities:

- Ice storage and processing (i.e., melting protocols) for basic biogeochemical parameters: biomass, nutrients, microbial community, organic matter, carbonate chemistry, gas concentrations, and primary production.
- Gas exchanges: gas-flux chambers vs. eddy covariance methods.
- Primary Production: a comprehensive critical analysis of the perceived strengths and weaknesses of the methods used to date.

These syntheses will allow us to define the needs for further intercalibration experiments, to test and validate our concepts and assumptions about the methods.

Task 2: Design and coordinate intercalibration excercises (years 1-4)

We will design specific intercalibration experiments to produce funding applications at both national and international levels for intercalibration experiments in readily accessible sea-ice locations (Cambridge Bay, Canada (lead B.T. Else); Tvärminne zoological station, Finland (lead J.-M. Rintala); and Saroma-Ko lagoon, Japan (lead D. Nomura)), as well as joint experiments at the ASIBIA (Atmosphere-Sea-Ice-Biogeochemistry in the Arctic) mesoscale chamber facility at the University of East Anglia (lead J. France). Our initial priorities will be:

- Comparison of storage conditions and the processing of sea ice for accurate determination of basic biological and biogeochemical parameters.
- Comparison of the available methods (including emerging techniques) to assess primary production in sea ice: isotopic tracer incubations, O_2 fluxes by under-ice microelectrodes and eddy covariance, O_2:Ar budgets, and biomass accumulation. We will also assess the most suitable tracer incubation protocols for general metabolic rate determinations in sea ice (e.g., bacterial production, nutrient transformations). That is, how to collect a representative in-situ sea-ice microbial community and to ensure tracer homogenization within the brine network prior incubation.
- Comparison of the available methods for determining $p CO_2$ in sea ice. Preliminary experiments comparing results from in-situ silicone chambers, solid-headspace equilibration, and calculations based on analyses of brines and melts could be conducted under controlled laboratory conditions. However, complex, high-molecular weight organic matter, as well as precipitated carbonate minerals, likely impact measurements of $p CO_2$ in natural sea ice, and therefore, parallel intercalibration experiments will also be required at one or more of the field sites.

We hope to organize our third meeting in conjunction with an intercalibration excercise. If we are sufficiently successful in raising supplementary funding, we aim to hold that meeting in Cambridge Bay, Canada; Tvärminne zoological station, Finland; or Saroma-Ko, Japan. Otherwise, we would hold the meeting at the experimental sea-ice facility, at the University of East Anglia. Funding for access to the ASIBIA chamber facility has already been solicited through a European Research Council large consortium proposal (EUROCHAMP 2020). A funding decision for EUROCHAMP 2020 is anticipated in mid-to-late 2016.

Task 3: Produce a framework for a living guide of best practices for sea ice biogeochemical studies (years 3-4)
Throughout the lifetime of the working group, we will explore and experiment with frameworks for disseminating the evolving understandings of the best approaches to measure biogeochemical parameters in sea ice in a format that is open-access and updatable. This framework might be hosted on the BEPSII, CliC, or SOLAS websites and will include the strengths and weaknesses associated with each method. The first large-scale implementation and testing of this guide to best practices will be during MOSAIC, a one-year time-series in the central Arctic Ocean scheduled for 2019-20.

Deliverables

- Individual review papers on strengths, weaknesses, and uncertainties in the methods used to process and store sea-ice samples before analysis, as well as measurements of primary production in sea ice and gas fluxes over sea ice.
- Concrete, executable designs for intercomparison and intercalibration experiments on ice processing and storage, primary production and incubation methods, gas fluxes, and

CO_2 partial pressure of sea ice.

- Recommendations for evaluation of spatial variability in sea-ice characteristics, based on traditional transect and nested sampling strategies coupled with new non-destructive technologies.
- Web-based framework for dissemination of evolving standards of best practices.
- Sea-ice biogeochemical sampling plan and recommended protocols for the 2019-2020 MOSAiC expedition, and other programs that follow it.

Capacity Building

Reliable measurements are a necessity if we want to properly describe the changes and forcing in the global environment and climatic system, in general. Our main goal is to provide the international sea-ice research community with standardized protocols for collecting, preserving, and processing sea-ice samples. The tasks we have described contribute directly to a long-term goal of accurately sensing variations in polar regions, which are among the environments most sensitive to ongoing global change. In addition to our immediate goal of informing the MOSAIC science plan (Task 3), the protocols ECVice will develop will contribute directly to the efforts of all long-term programs coordinating research in the polar oceans, including SOOS (the Southern Ocean Observing System), SCAR (the Scientific Committee on Antarctic Research), and IASC (the International Arctic Science Committee), as well as GCOS.

Support of young scientists is in the genes of ECVice. More than half of the proposed full members are less than 35 years old. The young scientists involved in this working group have carried out pioneering work on sea ice, establishing creative new methods to assess key variables at the beginning of their carriers. With the mentorship of the senior scientists in this working group, these young scientists are in a position to discuss and refine these innovative methods to produce widely-acceptable, extensively tested standardized protocols, a prerequisite for long-term coverage of these variables. The proposed membership of the working group also includes young experts in sea-ice analyses (i.e., trace metals and genetics) which are not among our focused list of initial priorities, but have, nonetheless, been identified as requiring intercalibration and intercomparison [Miller et al., 2015]. Our hope is that association with ECVice will also help those scientists develop the approaches needed to resolve their methodological issues.

We will also pass this consolidated expertise to new scientists interested in sea ice through a collaboration with a planned international sea-ice summer school to be held in Longyearbyen, Svalbard (to be organized by the BESPII SOLAS-CliC consortium). We hope to hold one of our annual meetings in conjunction with that summer school, with working group members delivering lecturers.

We are also committed to encouraging sea-ice research in nations with emerging polar research programs. Unfortunately, polar research, including investigations of sea-ice biogeochemistry, is still largely an endeavour of wealthy nations, and this is reflected in the proposed membership list. Despite our difficulties in identifying many suitable candidates from developing nations for initial membership in this working group, we will continue to actively seek out and support new sea-ice researchers working in countries that do not already dominate in polar research. Along these lines, we hope to hold at least one of the annual meetings in Asia and include teaching activities. We also hope to invite a few young scientists from under-represented countries, including Russia, to Saroma-Ko, Japan, in conjunction with our intercalibration experiment there, for a short course to expose them to the study of sea-ice biogeochemistry (e.g., through funds from the Japan Society for the Promotion of Science, as well as other sources).

Collaboration with Arctic communities is also fundamental to sea-ice research, and our plan to hold one of our intercalibration experiments in Cambridge Bay (Nunavut, Canada) will provide ECVice with an ideal opportunity to further that collaboration. Cambridge Bay is the location of the Canadian High Arctic Research Station (CHARS), which will be completed in 2017. Once operational, CHARS will employ numerous staff researchers, many of whom will be hired from Arctic communities, who will be tasked with monitoring aspects of the Arctic marine ecosystem and cryosphere. We will integrate CHARS staff scientists into our operations to help build their capacity to accurately measure essential climate variables in sea ice. We will also report back to CHARS the results of our intercalibration experiments to help ensure that the progress we make is integrated into the long-term monitoring conducted at the station. During our work in Cambridge Bay, we will also employ student assistants from Nunavut Arctic College's Environmental Technology Program. By involving these students we will be building the capacity of Inuit scientists to lead and participate in future Arctic research activities.

Working Group composition.

Full Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Daiki Nomura (co-chair)	Male	Hokkaido University, Japan	Gas concentrations and fluxes
2 François Fripiat (co-chair)	Male	Max Planck Institute for Chemistry, Germany (until June 1st 2016, Vrije Universiteit Brussel, Belgium)	Primary production and nutrient cycles
3 Brent Else (co-chair)	Male	University of Calgary, Canada	Gas fluxes, primary production, and emerging technologies
4 Bruno Delille	Male	Université de Liège, Belgium	Gas concentrations and fluxes
5 Mar Fernandez-Méndez	Female	Norwegian Polar Institute, Norway	Primary production, Microbiology
6 Lisa Miller	Female	Institute of Ocean Sciences, Fisheries and Oceans Canada, Canada	Gas concentrations and fluxes, Geochemistry
7 Ilka Peeken	Female	Alfred Wegener Institute Helmholtz Center for Polar and Marine Research, Germany	Primary production, microbiology

8 Janne-Markus Rintala	Male	University of Helsinki, Finland	Primary production and microbiology
9 Maria van Leeuwe	Female	University of Groningen, Netherlands	Primary production, microbiology
10 Fan Zhang	Female	Polar Research Institute of China, China	Microbiology

Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Katarina Abrahamsson	Female	Göteborgs Universitet, Sweden	Gas fluxes
2 Jeff Bowman	Male	Lamont-Doherty Earth Observatory, USA	Genetics, Microbiology
3 James France	Male	University of East-Anglia, UK	Gas fluxes Sea ice optics
4 Agneta Fransson	Female	Norwegian Polar Institute, Norway	Gas concentrations and fluxes, microbiology, nutrient cycles
5 Delphine Lannuzel	Female	University of Tasmania, Australia	Trace metals
6 Brice Loose	Male	University of Rhode Island, USA	Gas fluxes
7 Klaus Meiners	Male	Australian Antarctic Division, Australia	Primary Production, microbiology, and emerging technologies
8 Christopher J. Mundy	Male	University of Manitoba, Canada	Primary production, emerging technologies
9 Hyoung Chul Shin	Male	Korea Polar Research Institute, Korea	Microbiology
10 Jean-Louis Tison	Male	Université Libre de Bruxelles, Belgium	Gas concentrations and fluxes, physics

Working Group contributions

Daiki Nomura (co-chair): Dr. Nomura's research focuses on the carbon cycle within the ocean-atmosphere system, especially in the polar oceans. He has studied sea ice in the Southern Ocean, the Arctic Ocean, and the Sea of Okhotsk, in addition to conducing laboratory experiments on sea-ice freezing processes.

François Fripiat (co-chair): Dr. Fripiat's primary interest is in the application of stable isotopes (N, Si, C, O, …) to unravel biogeochemical cycles both in the modern and past polar oceans. He uses both natural variations of isotopes and isotopic-tracer incubations.

Brent Else (co-chair): Dr. Else's primary interests are in gas exchange across the ocean-ice-atmosphere interface, with particular expertise in the use of eddy covariance techniques, both for atmospheric and underwater gas flux measurements. His strong connections to the Canadian High Arctic Research Station and other research organizations located in Cambridge Bay will allow him to facilitate collaborative field research activities in the region.

Bruno Delille: Dr. Delille's research focuses on gases dynamics within sea ice. Since 1999, he has participated in numerous bipolar sea-ice field surveys and sea ice tank experiments, using both extractive and in-situ methods.

Mar Fernández-Méndez: Dr. Fernández-Méndez is a marine microbiologist with a special interest in carbon and nutrient uptake rates, and her current work is focused on sea-ice algae and phytoplankton primary productivity in the Arctic Ocean. She is actively involved in field campaigns every year and is engaged with development and training of early career scientists.

Lisa Miller: Dr. Miller is a classically trained analytical chemist whose research focuses on the role of sea-ice in controlling air-sea partitioning of climatically active gases. She currently serves on the Scientific Steering Committee of the Surface Ocean-Lower Atmosphere Study, as an advocate for polar research, and she was co-lead of the methodologies task group of SCOR Working Group 140 on Biogeochemical Exchange Processes at Sea-Ice Interfaces.

Ilka Peeken: Dr Ilka Peeken is trained as phytoplankton ecologist with a broad experience in the investigation of sea-ice covered pelagic ecosystems with a recent focus on the effect of climate change on sea ice biota in the Arctic Ocean. She conducted and led sea-ice field campaigns in the Arctic and is actively involved in writing the science and implementation plan of the field campaign MOSAIC.

Janne-Markus Rintala: Dr. Rintala is specialized in species identification, i.e., he has described a new cryptophytes (*Rhinomonas nottbecki*), a new dinoflagellate subspecies (*Heterocapsa arctica* subsp. *Frigida*) and a new cyst *Scrippsiella hangoeii*. In addition to field work he has been doing experimental research as well, i.e., investigating the dark survival and photosynthetic efficiencies and published a methodological comparison that is confronting the earlier methods used for melting sea ice samples. Currently he has become interested in identifying key species responsible for gas exchange and CO_2 uptake as well as DMSP production.

Maria van Leeuwe: Dr. van Leeuwe is marine biologist with a specific interest in the photophysiology of microalgae. She is currently working on the application of the stable isotope ^{13}C in tracing carbon fluxes in sea-ice ecosystems.

Fang Zhang: Dr. Zhang is marine ecologist with special interest in microbiology. Her current work focuses on sea-ice biota in the Arctic Ocean, including community composition and diversity, their environmental correlations, and gene functions.

Relationship to other international programs and SCOR Working groups

This proposed working group is a direct follow-up to a broad review of methods used to study sea-ice biogeochemistry [Miller et al., 2015], which was a product of SCOR Working Group 140 on Biogeochemical Exchange Processes at Sea-Ice Interfaces. That paper clearly identified a number of methodological uncertainties that could be resolved by further focused, international coordination. This new proposal is supported by BEPSII, a newly designated network on sea-ice biogeochemistry that is sponsored by both the Climate and Cryosphere (CliC) program and the Surface Ocean-Lower Atmosphere Study (SOLAS).

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SCOR Working Group Proposal

(max. 6000 words, excluding Appendix)

1. Title: Building a coral reef marine biodiversity observation network

2. Acronym: CoralMBON

3. Summary/Abstract (max. 250 words)

Coral reefs are among the most biodiverse, socio-economically important and threatened ocean ecosystems, facing a potential global collapse under the combined local and global threats imposed by the worlds' growing population. The working group's aim is to provide the technical foundation for identifying Essential Variables (EVs) that describe the status and trends of coral reefs, and build capacity in the Global Coral Reef Monitoring Network (GCRMN) to provide regionally and globally consistent data and indicators on reefs. This will help to consolidate and advance research on reef processes and futures, and support management and decision-making to conserve reefs from local to global levels.

The working group will identify and refine EVs across the six Essential Biodiversity Variable classes set by GEOBON (starting with live coral cover), and provide guidance for the GCRMN to become a mature observing system and part of the international marine Biodiversity Observation Network (MBON). By integrating this work with ongoing reporting on reefs by GCRMN regions, the working group will build capacity in the monitoring teams and regional networks of developing countries. Outputs will include specification sheets and manuals that define EVs and how to produce them, and papers in open access journals. By working within the institutional framework of the GCRMN and the International Coral Reef Initiative, the working group will leave a lasting legacy. The working group will facilitate improved reporting of coral reef health relevant to Aichi Target 10 on climate vulnerable ecosystems, and thereafter of relevance to the Sustainable Development Goals.

4. Scientific Background and Rationale (max 1250 words)

The vulnerability of coral reefs to the current combination of local and global stressors, including climate change, is very high (Spalding and Brown 2015), and the societal need and priority level for conserving reefs is high. Coral reefs occupy less than 0.25 % of the ocean, host > 25% of all known marine fish species, and 32 of the 34 recognised animal Phyla. Coral reefs are found in 109 countries, all tropical and mostly developing, with more than 450 million people living within 60 kilometres of them. A healthy reef can yield up to 15 tonnes of fish and other seafood per km^2 each year, and benefits lost from degraded reefs are estimated as high as US$137,000-1,200,000 over a 25-year period. Yet human pressures have driven 27% of the world's coral reefs into severe decline, and if present rates of destruction continue, 60% of the world's coral reefs will be destroyed over the next 30 years. The importance of coral reefs is highlighted in their prominence in the Strategic Plan for Biodiversity of the Convention of Biological Diversity (Aichi Target 10), the recent decision by COP12 on Priority Actions for Coral reefs (https://www.cbd.int/doc/publications/cbd-aichi-target-10-en.pdf) and in the UNFCCC's recognition of coral reefs as an indicator ecosystem of the first irreversible impacts of climate change on planetary biota (Gatuso 2014).

A number of initiatives are converging on the need to establish a global and robust observing and reporting system for coral reefs, which will serve to report on success or failure in reversing the decline of coral reefs and help identify necessary actions to achieve societal and national goals with respect to coral reefs. The Global Ocean Observing System (GOOS) Biology and Ecosystems Panel, considering among other things the societal drivers and pressures requiring sustained observation of biological ocean variables, has identified “live coral cover” in the top two of nine priority Essential Ocean Variables. The Global Coral Reef Monitoring Network (GCRMN), hosted by the International Coral Reef Initiative (ICRI, http://www.icriforum.org), has generated global and regional reports on coral reef status and trends since 1998 and is poised to revitalize and upgrade its approach following a regional report completed for the Caribbean (Jackson et al. 2014). Historically done through writing teams aggregating from national to global levels (e.g. Wilkinson 2008), the GCRMN is ready to put in place a more robust regional analytical process (ICRI 2015). Further, while coral cover is recognized as the prime variable for reporting reef status, and is justifiably proposed as one of the first EOVs (see above), on its own it provides a very narrow picture of the status of such a diverse and complex ecosystem (Hughes 2010); the identification of other variables (see Jackson et al. 2014) across the full range of Essential Biodiversity Variable (EBV) classes (Pereira 2013, http://geobon.org/essential-biodiversity-variables/ebv-classes-2/) would provide an immeasurably stronger basis for decision-making on coral reefs, from local to global scales.

As in many sciences, focused effort and investment is needed to open up existing communities of practice and bridge gaps across them. The GCRMN has paved the way for standardization, but debates persist about methods and focus (see Jackson et al. 2014), particularly with emerging challenges and threats such as climate change. Further, rapidly emerging technologies that are revolutionizing methods and data collection, need to be considered to maintain long time series of data that provide appropriate pre-impact baselines for assessing change. Practices developed in the climate and open ocean observing communities (through the Global Climate Observing System and GOOS-OOPC), in terrestrial biodiversity fields (in GEOBON) and in other marine systems under the GEOBON MBON umbrella (see UNESCO 2012, GEOBON undated) provide templates to streamline the next stage of development of the GCRMN.

A SCOR WG provides an unparalleled opportunity to bring these communities of practice together, combining the expertise and approaches across different global science communities, and integrating the experience gained by different field-based scientific and monitoring groups. SCOR funds target such scientific innovation and integration with observing systems, where other funding sources focus on primary research or conservation outputs. The emerging focus on Essential Variables (Bojinski 2014, Pereira 2013), which address the scientific output and societal benefit of a monitoring programme, provides a clearer path to integration across different contributors that is relevant for coral reefs. The SCOR WG will contribute to ocean science by a) identifying and developing mature Essential Ocean/Biodiversity Variables (EVs) for coral reefs that comply with the GOOS and GEOBON criteria (UNESCO 2012, GEOBON undated), and b) building capacity at regional and global levels in a coral reef observing network, for EV generation, data use and access, and interoperability. In doing so, the group will set a new foundation for longer term collaboration in the coral reef observing and reporting communities, and provide direction for the next steps in fundamental science supporting this development.

The urgency for this working group’s outputs is high, both from push and pull factors. Currently, coral reefs are experiencing a global coral bleaching event that began in 2015, and is impacting the Caribbean, parts of the Pacific, the Great Barrier Reef and the Indian Ocean. This global event highlights the need for a strengthened observing system that incorporates forecasting to anticipate major threats, and to measure their impact. The broader beneficiary community that will use improved coral reef observations and reporting extends from the national to global reporting frameworks for biodiversity and organs relating to them (including the Convention on Biological Diversity (CBD) and the IPBES), to the biodiversity and natural resource management and conservation communities aligned through the International Union for the Conservation of Nature

(IUCN) (including states, non-government organizations and communities/stakeholders). Already, the GCRMN is the de facto reporting mechanism used by these groups, such as in the Global Biodiversity Outlook 4, and in IUCN Red Listing for coral reef species. Yet its lack of standards and procedures for data quality and processing, and aggregation to higher levels undermine the reliability of the outputs (GBO 4, Tittensor 2014). Providing standards that raise confidence and credibility in these outputs will be a key contribution of the SCOR WG to both science and societal goals.

Work will focus at regional scales, matching the driving forces and large-scale dynamics of coral reef systems, and strengthening existing processes. The UNEP Regional Seas programme was designed around the regional oceanographic processes that control coral reefs, and provides a template on which ICRI and the GCRMN operate. The working group will work with the GCRMN's existing regional reporting processes. Currently, reporting is underway or planned in the Western Indian Ocean (2015-16) Pacific (2016-17), Eastern Tropical Pacific (2016-17) and Southeast Asia, and the goal is to complete reporting in all coral reef regions by 2020 and contribute a global update to assess achievement of the CBD's Aichi Target 10. The regional approach will enhance sustainability of actions after the end of SCOR support, and will also provide a platform for addressing emerging research questions at the regional scale (e.g. on disease, invasive species and cascading effects of climate change and global resource (fish) extraction).

While social science and socio-economic monitoring are necessary to develop effective management and interventions to maintain coral reef health (see GCRMN's SocMon programme – http://www.socmon.org/), they are beyond the scope of this first stage of work. They will thus not be covered by the working group, but recommendations for applying the lessons learned from this WG to socio-economic monitoring will be considered at the conclusion of this group.

5. Terms of Reference (max. 250 words)

1. Define and publish guidance on coral cover as an Essential Ocean/Biodiversity Variable (EV) in an EV specification sheet and a community methods paper in an open access journal.
2. Identify concept & pilot EVs for coral reefs and prepare time-bound workplans led by a WG member to develop and describe them as mature EVs.
3. Strengthen the Global Coral Reef Monitoring Network to become a mature ocean observing platform supplying coral reef Essential Variables to the global community, and link this to the international MBON under GEO BON (i.e. develop a crMBON)
4. Establish open data, reporting and dissemination principles and mechanisms that facilitate access to and use of coral reef EVs for decision-support tools (e.g. IUCN Red Lists, UN World Ocean Assessment, IPBES) and reporting on coral reef health (e.g. CBD Aichi Target 10).
5. Establish a portal for coral reef EVs linked to OBIS, facilitating open access to EVs and to the science and monitoring community that provides them.
6. Build capacity in regional observing and reporting networks (the nodes of GCRMN) as the primary mechanism for sustaining coral reef EV generation.
7. Expand GCRMN communications and publications to support regional capacity building and reporting, EV development and communications relevant to decision-makers.

6. Working plan (logical sequence of steps to fulfil terms of reference, with timeline. Max. 1000 words)

Part I, EVs – Draft specifications for live coral cover, and supporting EVs are being developed by GOOS-BioEco in 2016. These will be expanded through scientific consultations in 2016 providing a first set of variables for the WG to classify as concept, pilot or mature (UNESCO 2012, GEOBON undated), and subsequently identify how to move each one up the maturity scale. Each EV will be classified through the following steps:

A. Institutional relationships: describe the current state, and necessary improvements for an oversight group, expert teams and implementation communities.
B. Methods and data provision: describe the current state of monitoring using the DPSIR framework of the FOO:
    1. inputs –the requirements for observations, focused on scientific and societal priorities;
    2. processes – the monitoring teams, their methods and the variables that they produce, and processing steps to generate coral reef EVs.
    3. outputs – using EVs to calculate further output variables, accessibility of the EV to user communities from local to global levels, reporting and products that will benefit both science and society, and the needs identified in 1).
C. Score A and B into the three levels of maturity: concept (ideas are articulated and peer-reviewed), pilot (aspects of the system are tested and made ready), and mature (the system is scaled and reliable, is a sustained part of the global ocean observing system). Each of these have 3 sub-levels defined (UNESCO 2012) – use these to facilitate identification of manageable steps to upgrade each component of the observing system.

The GCRMN use field-based monitoring methods, which can contribute to certain EVs and EBV classes, for example coral cover as measure of ecosystem structure (EBV class 6). The WG will distinguish those EVs that can be supplied by the GCRMN, from those requiring different methods (e.g. genetics). Tools already available in BON in a Box will be used and developed to support analyses.

For the GCRMN-compatible EVs:

- identify/select the mature EVs to update the scope of the GCRMN, and identify targets to upgrade regional GCRMN programmes to full maturity;
- for EVs in a concept or pilot phase, identify steps to improve them to mature status, providing guidance for implementation teams and regional networks to build capacity;
- write a community methods paper in an open access journal consolidating the description of the EVs and their input variables and methods, with a component on improvements and innovations that currently do, or soon may, improve data provision.
- obtain certification for the GCRMN as an operational observing system under GOOS, and as a coral reef BON under the broader Marine BON.

For the non-GCRMN EVs, WG members active in those fields will form sub-groups (co-opting new members if needed) to identify key research and prepare workplans to advance the EVs to mature status, and organized as the coral reef component of MBON (i.e. crMBON). The responsibility to raise additional resources for these sub-groups will be theirs, leveraged by their status on the SCOR WG. Publications by these sub-groups will be specified in their workplans.

Workshop 1 will be held early in year 1, to establish common ground for the WG members, focus on the EVs for which the above work will be undertaken, and confirm planned actions for years 2 and 3. A potential venue may include Fiji, aligned with the First Triennial Oceans and Seas Global Conference (June 2017), in a GCRMN region undergoing its reporting process, or coinciding with an ICRI General Meeting.

Part II, Open data – there is no common or open access data system for key coral reef variables that are critical for management and decision-making. Based on open data principles, data publishing and Creative Commons standards, the WG will identify mechanisms to make coral reef EVs open access and available through an online resource/portal (to be resourced separately). Past and existing systems (Reefbase, Coral Triangle Initiative, COREMO, and a new French database, BD-ROI) will be assessed to inform this process. Synergies would be clear with portals such as the Ocean

Biogeographic Information System (OBIS), and a proposed coral reef portal under the CBD Secretariat to support Decision XII/23 on Priority Actions for Coral Reefs. To further enhance access to the data and its use by decision-makers (e.g. in national government or regional institutions), score cards will be developed for GCRMN teams to report on their data, presenting only the higher-level results/outcomes based on the small set of EVs.

The data system and processing tools, requirements for a portal and completing EV work from Part I will be the focus of Workshop II, to be held in the middle of Year 2. Similar criteria will apply to selecting a venue for workshop II, and/or the 4th World Conference on Marine Biodiversity (WCMB) in Montreal, Canada (May 2018) will provide access to global representation of scientists and students, and to the Secretariat of the CBD.

Part III, Dissemination & Publications – the WG will strengthen the publication series of the GCRMN producing the outputs listed in the deliverables section (#7). Some of these publications will be built up in years 1 and 2 and output progressively, while the full publications/output plan will be completed in year 3 and workshop 3, though publication of some items will take longer. The online data portal (Part II) will assist by maintaining all publications in one place, as well as on www.icriforum.org, and may have capability for data enquiry and output of simplified, user-generated score cards.

Workshop 3 will be held in 2019, in conjunction with a Chapman Conference, or another major international conference. It will project the findings of the WG to the global policy domain, and will be held in an influential country providing high level support for the work in ICRI (and/or the CBD). It will be used to prepare a global report on coral reef status for release in 2020, to coincide with reporting on CBD Aichi Target 10.

7. Deliverables (state clearly what products the WG will generate. Should relate to the terms of reference. Max 250 words). A workshop is not a deliverable. Please note that SCOR prefers that publications be in open-access journals.

Deliverables will be published on the WG's online portal (as well as on the GOOS and relevant GEOBON websites, and CBD coral reef portal where relevant) as well as through additional channels specified for each one.

a) Essential Variable (EV) specification sheets, focused on the EVs produced by different monitoring systems, and addressing the inputs, monitoring elements and outputs for each. From a global template (Part I), the WG will work with regional nodes to prepare regional EV specification sheets, revealing explicit steps to upgrade each region;
b) Community methods papers specifying the main EVs, their supporting EVs, and the families of methods currently accepted/used to supply them. Starting in year 1, we will propose a special topic in *Frontiers in Marine Science* under which the full series of peer-reviewed publications of the GCRMN and SCOR WG can be published, planned to continue the series/topic into the future.
c) A GCRMN/SCOR/GOOS/GEOBON technical series, building on the existing GCRMN reports (global and regional), focused on implementation of methods and upgrading regional GCRMN networks to mature level. These form a grey literature tier below the peer-reviewed publications in b) above.
d) Communications products targeted at end-users, such as score cards for decision makers, facilitating their access to key information useful in their contexts.
e) Policies and manuals for EV production adopted under the institutional umbrella of the GCRMN and the International Coral Reef Initiative, and accredited by GOOS and GEOBON.

8. Capacity Building (How will this WG build long-lasting capacity for practicing and understanding this area of marine science globally. Max 1500 words)

Regions are the primary geographic scale at which coral reef policy and implementation mechanisms are most coherent, and are the priority scale for GCRMN implementation and reporting (ICRI 2015). Many coral reef regions lack scientific and analytical capacity; the FOO/GEOBON criteria and standards established in this WG will enable step by step improvements to build more mature regional monitoring systems, and to build scientific and analytical capacity. Capacity building will be targeted under two themes of the WG – one focused on GCRMN monitoring structures to improve their outputs as observing systems (FOO criteria), and the second focused on building broader scientific capacity in the technical areas required for producing non-GCRMN EVs.

The main vehicles for capacity building will be:

- Workshops 2 and 3 (criteria for selection of the locations will include opportunities for inclusion of additional participants, additional activities such as WG members participating in training events, giving lectures, etc., and the location of a Chapman Conference if one is approved);
- Targeted outputs of the working group (EV spec sheets, guidelines for implementation/ upgrading of a GCRMN monitoring teams (observing elements) and regional networks;
- Embedding of the WG in regional and global mechanisms that sustain networking and capacity building (GCRMN, GEOBON, GOOS/UNESCO-IOC, CBD at global levels, and regional mechanisms such as the Nairobi Convention's Coral Reef Task Force and Indian Ocean Commission's Reef Network in the Western Indian Ocean).
- Online materials will be developed in Parts II and III, and the potential for a MOOC to be developed can be explored. A coral reef portal mandated by the Convention on Biological Diversity's Decision on Priority Actions for Coral reefs may provide a venue for capacity building materials (https://www.cbd.int/doc/publications/cbd-aichi-target-10-en.pdf).

GCRMN EVs – GCRMN implementation teams operate within countries, often under a national network which itself is part of a regional GCRMN node or network. The WG outputs will address standards relevant to all of these levels (i.e. dealing with inputs/objectives, monitoring elements and outputs/publications), and will assist the GCRMN in training team members at all levels of the network. Regional and key national leaders within regional GCRMN teams will be invited to participate in the WG workshops, collaborate with different WG members and/or participate in ICRI General Meetings and other events (e.g. ITMEMS). Taking advantage of their active engagement, workshops 2 and 3 will also be held in regions actively undertaking GCRMN reporting. One of the tasks of the ICRI representative(s) in the WG will be to coordinate this capacity building function and identify further support to sustain it.

Non-GCRMN EVs – the sub-groups leading the development of new coral reef EVs will generally be focused in developed or emerging country research institutions and/or their primary field locations where their active research is focused. Capacity building will target extending this capacity for research to coral reef regions that don't yet have this capacity, and through this, extend the geographic range over which the EV can be supplied. This may occur through promoting collaborations across regional boundaries (e.g. through graduate students and post-docs) to build research capacity. This will broaden and deepen the coral reef biodiversity observation network in coming years, as capacity grows.

Specific outputs from the working group that focus on capacity building will include the following:

- EV specification sheets, as these will provide globally standardized information on complementary and supporting variables to the EOVs, their requirements, observing networks and elements, data and information management, and readiness for global implementation.
- Monitoring manuals, expanding on the methods described in the scientific publications of the WG, building on the existing GCRMN series of manuals. These will also be targeted with other supporting capacity building networks in mind – at global levels (UNESCO-IOC, POGO, ITMEMS), and regional levels (e.g. for the Western Indian Ocean, the ODINAFRICA regional network, the International Indian Ocean Expedition 2, and the Western Indian Ocean Marine Science Association (WIOMSA) are all relevant regional mechanism supporting science capacity building. Similar mechanisms will be identified for other GCRMN regions, with a focus on those undertaking reporting for the GCRMN).
- Online data tools and a portal that holds all the above. The specifications for this will be identified in Part II.

Workshop II and III will be structured around the following options:

- Working group meeting – 2-3 days
- Monitoring methods workshop for national/regional team members, offered by 2-3 of the WG members, for 2-3 days before or after the WG meeting
- Participation in a larger conference (e.g. Chapman Conference) around which the WG meeting is planned, to present findings of the WG to a broader community. This could include at least one presentation on the WG itself, and potentially more presentations by WG members on their own contributions around GCRMN strengthening and/or EV development.
- ICRI General Meeting, or an ITMEMS – participation by some WG members and key national/regional leaders that attend the trainings.

9. Working Group composition (as table).

Full members

1. David Obura (chair)	Male	CORDIO East Africa, Kenya	Reef ecologist, focused on coral biogeography, bleaching and recovery; experience in monitoring and methods development; involvement in science-policy processes
2. Aldo Cróquer	Male	Simón Bolívar University, Venezuela	15 years working on coral reef monitoring programs in Venezuela and across the wider Caribbean. Selection of essential variables for observing and/or reporting trends of coral reef decline & recovery at local and regional scales. Delivering scientific evidence to managers and policy makers in the wider Caribbean.
3. Claire Bissery	Female	IFRECOR, France	Marine ecologist, specialised in data processing and management. Experience in Reef Monitoring data analysis and MPA effectiveness.
4. Jörg Wiedenmann	Male	Coral Reef Laboratory, University of	Full professor, working on nutrient effects on reef corals and the interactions with environmental stress, linking molecular mechanisms to

		Southampton, UK	changes at the ecosystem level.
5. Joshua Madin	Male	Macquarie University, Australia	Leader of the Coral Trait Database; work in quantitative ecology and ecological informatics
6. Maria Dornelas	Female	University of St Andrews, UK	Biodiversity quantification, eco-informatics, big data, coral diversity
7. Mark Eakin	Male	US National Oceanic and Atmospheric Administration, USA	Coral reef ecology, especially environmental remote sensing of coral reefs, the impact of climate change on coral reefs, coral bleaching, ocean acidification, oil spills, coral paleoclimatology, and the behavior of marine organisms
8. Mary Donovan	Female	University of Hawaii, Honolulu HI USA	Analysis of monitoring data, development of databases, participation and knowledge of GCRMN networks, background in resilience, tipping points, indicator development
9. Rohan Arthur	Male	Nature Conservation Foundation, India	Marine Ecologist with an interest in social-ecological systems and system resilience to climate change and other stressors.
10. Vivian Lam	Female	University of Queensland, Marine Spatial Ecology Lab (to end 2016) (Hong Kong)	Previous deputy coordinator of the Global Coral Reef Monitoring Network and IUCN Marine Programme Officer (2010-2013), involving collating data from contributors, workshop organization, and compiling the Caribbean regional report.

Associate members

1. Elizabeth Mcleod	Female	The Nature Conservancy, USA	Impact of climate change on coral reef ecosystems, climate modeling, resilience assessments, coral bleaching, coral reef resilience, ocean acidification, blue carbon, developing tools and guidance for managers to address climate impacts and other stressors on reefs
2. Francis Staub	Male	France and UK	Consultant with 15 years of experience working for ICRI and its networks. Strong network with the coral reef stakeholders (International Development Agencies, governments, NGOs, donors…). Currently providing technical assistance to the French and Madagascar governments, as co-chairs of the ICRI Secretariat.
3. Frank Muller-Karger	Male	University of South Florida, USA	Marine biodiversity and ecology, in situ and remote sensing of coral reefs including geomorphological mapping using medium resolution satellite imagery and coarse resolution multidisciplinary observations (ocean color, temperature,

			winds, etc.) and evaluations of coral reef health.
4. Hugh Sweatman	Male	Australian Institute of Marine Science	A broad interest in coral reef ecology and extensive experience with collecting and interpreting reef monitoring data and communicating to reef managers
5. Jerker Tamelander	Male	UNEP Coral Reef Unit, Thailand	Research focused on reef recovery and resilience, role with UNEP and previously with IUCN supporting and promoting applied research, marine and coastal management and policy development at international as well as national level, for conservation and sustainable use of coral reefs that benefits dependent people and economic sectors.
6. Karen Chong-Seng	Female	Seychelles Islands Foundation (until 30th April 2016)	Ecological structure and processes on disturbed coral reefs, evaluating the coral reef monitoring programme for Aldabra Atoll World Heritage Site.
7. Ruth Gates	Female	University of Hawaii, USA	My research group focuses on defining biological traits driving differences in performance among corals and reefs. Our goal is to contribute new knowledge and discuss how this can translate to solutions that can help preserve, manage and conserve reefs.
8. Serge Planes	Male	CRIOBE, Moorea, French Polynesia	Reef ecologist with expertise on evolution and genetics, and fish monitoring. Director of coral reef monitoring programs and observatory.

10. Working Group contributions (max. 500 words)

Detail for each Full Member (max. 2 sentences per member) why she/he is being proposed as a Full Member of the Working Group, what is her/his unique contribution?

David Obura developed this concept to strengthen GCRMN as a mature ocean observing system that responds to societal needs expressed in local management and convention terms. Will contribute on aspects of coral species, cover and resilience; in the overarching goals and integration of the group across different EBV classes; and institutionalizing outcomes in the GCRMN/ICRI.

Aldo Cróquer 15 years experience on bleaching, disease, trends of decline, recovery and/or stability, across the Caribbean. Has cooperated with the GCRMN to produce annual reports on the status of coral reefs in the South Tropical Americas, and have coordinated local monitoring programs in Venezuela joining efforts with regional and global programs such as CARICOMP and GCRMN

Claire Bissery working with the French coral reef network (IFRECOR) to assure data entry in the national database (BD Récifs), data analysis and definition of indicators to evaluate the coral reef status. As France is ICRI's Secretariat for the 1st two years of the WG, will provide a supporting role to the group, embedding its contribution in ICRI and GCRMN institutional processes, and in regional GCRMN assessments in which France is involved.

Jörg Wiedenmann His research has produced paradigm-changing insights into the nutrient physiology of reef corals and how disturbance of the nutrient environment can increase the vulnerability of coral reefs to stress imposed by global warming. His molecular work has yielded high-content biomarkers to monitor nutrient stress in corals.

Joshua Madin will contribute in developing Essential Biodiversity Variables for coral reefs based on species-level traits, and bring analytical and database expertise to the working group.

Maria Dornelas havs led the assembly of the largest assemblage level biodiversity time series database (BioTIME) and have expertise at quantifying and modelling coral biodiversity.

Mark Eakin has been involved with the GCRMN since its start, including as past Chair of its Scientific and Technical Advisory Committee. As Coordinator of NOAA's Coral Reef Watch, He leads the team that monitors ocean temperatures that cause coral bleaching around the world as well as other environmental stresses to coral reefs.

Mary Donovan will bring my experience from GCRMN reporting in the Caribbean, as well as expertise in database design for coral reef monitoring, and analysis of complex data streams. Will also contribute knowledge of coral reef social-ecological systems, including experience developing indicator variables that are relevant to ecosystem and resilience-based management.

Rohan Arthur will contribute a perspective from some the most vulnerable low-lying atolls in the Indian Ocean, and is keenly interested in understanding how reef resilience can be maintained in even the most heavily populated reef regions. Is interested in exploring how local, governmental and non-governmental management can work together to enhance reef resilience in developing-world scenarios.

Vivian Lam Experience in gathering data for the Caribbean GCRMN and co-editor of the report, and will support the East and Southeast Asia GCRMN regional reporting on returning to Hong Kong after her PhD. My skills are in monitoring data analysis using a multivariate state-space approach to analyse key drivers in long term data.

11. Relationship to other international programs and SCOR Working groups (max. 500 words)

The relationship of the working group to the International Coral Reef Intiative (ICRI) and its monitoring network, the Global Coral Reef Monitoring Programme (GCRMN) has been highlighted in the proposal text. The working group will provide the technical expertise and direction for strengthening the GCRMN and upgrading it to standards developed under the GOOS Biology and Ecoystems Panel (GOOS-BioEco) and GEOBON's Working Group 5 on Oceans, and in particular the Marine Biodiversity Observation Network (MBON). Representatives from each of these institutions are in the working group, and many of the working group meetings will be aligned with ICRI General Meetings in particular, as well as with meeting of GOOS BioEco and GEOBON WG5/MBON. Support for this integration is recorded in meeting minutes from each of these programmes, such as in the ICRI General Meeting minutes from December 2015 (ICRI 2015).

No direct relation to existing SCOR working groups

12. Key References (max. 500 words)

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13. Appendix

SECTIONS IN APPENDIX

A. MEMBER PUBLICATIONS
B. NOTE AND CONTRIBUTIONS OF ASSOCIATE MEMBERS
C. LIST OF ACRONYMS

A) MEMBER PUBLICATIONS

Arthur

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B) ASSOCIATE MEMBERS

The roles and key publications for the associate members are also given here, as they a) will contribute equal expertise in the technical work of the group, and/or b) play a key role in participating institutions, serving to anchor the work of the group on those institutions for sustainability

ASSOCIATE ROLES (2 sentences, as for full members)

Francis Staub has been involved in technical support to all ICRI Secretariats since 1999, am a member of the GCRMN Management Group (in ICRI), and provide technical assistance to the secretariat of the UNEP-RSCAP Global Coral Reef Partnership (one of its objectives being to strengthen the GCRMN reporting through the UNEP Regional Seas programme). Thus, he will connect the work of the WG to other projects and supporting institutions, and focus on institutionalizing WG outcomes in GCRMN and ICRI.

Frank Muller-Karger is a member of both GEOBON WG5 and GOOS Bio-Eco working groups, and lead the Marine biodiversity Observation Network under GEO BON (MBON), which includes coral reefs will provide a technical base for the GCRMN strengthening, with ongoing work to identify essential variables for biodiversity observation in the oceans. He have led the CARIACO Oceanographic Time-Series program since 1996 with the goal of observing and understanding ecological and biogeochemistry changes in the Atlantic Ocean and the connection between surface oceanography and the flux of elements to the ocean bottom that preserves climate signals.

Jerker Tamelander will provide technical inputs on indicators, variables and reporting relevant to countries, Regional Seas Conventions and Action Plans and other international reporting processes that can also support management on the ground, based on extensive professional experience, current work at UNEP and with the Regional Seas. And institutional support from UNEP's Coral Reef Unit and Global Coral Reef Partnership to the working group in relation to UN processes, including the SDG indicator framework and the CBD Strategic Plan on Biodiversity (Aichi Targets), as well as on the role of the working group within ICRI, based on experience in GCRMN's Management Group and supporting strategic development of GCRMN.

Karen Chong-Seng has substantial experience working on coral reef monitoring, and assessing their condition – including using quantitative analyses. Moreover, has extensive experience in the Western Indian Ocean, with a focus on the inner granitic Seychelles and the outer, more isolated Aldabra Atoll.

Elizabeth Mcleod has worked building the capacity of reef managers to address climate change for fourteen years. She is the science lead for the Reef Resilience (RR) Network (www.reefresilience.org) which provides the latest guidance to help coral reef managers address climate change impacts and local threats and was instrumental in developing the RR toolkit and trainings which have trained nearly 1,500 reef managers in more than 75 countries. Has led resilience trainings across the Asia-Pacific region and modeled climate impacts on coral reefs across Indonesia and the Pacific.

Ruth Gates will bring her lab's experience in an "omics" approach (metabolomics, gene expression and transcriptomics, epigenetics, genomics), looking at coral response at scales from ecological to cellular, which helps us to better determine the extent to which corals will be able to adapt and acclimatize to climate change, to identification and development of Essential Biodiversity/Ocean Variables for coral reefs. She is the President of the International Society for Reef Studies, am organizing committee of the 13th International

Coral Reef Symposium, and has participated in or is currently leading a variety of International Synthesis efforts to improve connectivity among the coral reef science, agencies and stakeholder groups that will be networked with the work of the WG and GCRMN.

Hugh Sweatman has 20 years' involvement with the AIMS Long-Term Monitoring Program on the Great Barrier Reef, one of largest and longest running of such programs. This has necessarily involved issues of quality control, reassignment of effort to different questions, and program reviews, and he is currently involved in the development of an integrated monitoring program for the GBR.

ASSOCIATE PUBLICATIONS

Chong-Seng

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C) LIST OF ACRONYMS

CBD: Convention on Biological Diversity
EBV: Essential Biodiversity Variable
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
EV: Essential Ocean/Biodiversity Variable
FOO: Framework for Ocean Observing
GCOS: Global Climate Observing System
GCRMN: Global Coral Reef Monitoring Network
GEOBON: Group on Earth Observations – Biodiversity Observation Network
GOOS-OOPC: Global Ocean Observing System – Ocean Observations Panel for Climate
GOOS: Global Ocean Observing System
ICRI: International Coral Reef Initiative
IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
ODINAFRICA: Ocean Data and Information Network for Africa
UNEP: United Nations Environmental Program
UNESCO-IOC, POGO, ITMEMS), and regional levels (e.g. for the Western Indian Ocean, the ODINAFRIC
UNFCCC: United Nations Framework Convention on Climate Change
WIOMSA: Western Indian Ocean Marine Science Association

Global Assessment of Nutrient Export Through Submarine Groundwater Discharge (NExT SGD)

Figure 1: Submarine groundwater discharge in a coral reef in Lombok, Indonesia.

Summary

We propose to establish a new working group that will foster interactions between modelers on one hand and field observations and data collection scientists on the other. Through interactive meetings they will work together to *set the guidelines* *and needs for creating a data base* (including metadata) for the development of a new global model to assess nutrient and constituent export through submarine groundwater discharge (SGD) to *nearshore coastal areas* - the NExT SGD models (reflecting several different constituent fluxes). The proposed multi-national NExT SGD working group consists of scientists whose research crosses disciplinary boundaries including: hydrogeology, geochemistry, oceanography, and the global water cycle. Local data on SGD and associated nutrient fluxes is extensive in many regions and has increased exponentially during the last 15-20 years. For example, more SGD data is available now than what previously existed for rivers at the initial stage of the NEWS global river flux model 10 years ago and it is representative of a broad array of aquifer, coastal zone and climate regimes. To ensure the success of this working group, we will build on and interact with other working groups and programs (e.g., GEOTRACES, GlobalNEWS and LOICZ, UNESCO IHP, BCO-DMO) as well as specifically with members of the former SCOR group 112, "*Magnitude of Submarine Groundwater Discharge and its Influence on Coastal Oceanographic Processes*". Our working group will benefit from their experiences in compiling large databases, identifying and filling potential data gaps and developing and distributing protocols for best practices. The SCOR WG 112 focused on the validation of radiotracer techniques versus conventional hydrogeological approaches for assessing magnitude of water flux to coastal areas. It is in part due to the effort and findings of WG 112 that the radiotracer

techniques are now widely applied in local studies throughout the world. Building on the results of WG112, which focused SGD volume, the new group will set up guidelines for creating a uniform user-friendly database of literature data on both SGD quantity and quality that will be instrumental for building global models (the NExT SGD models) to estimate nutrient fluxes entrained by SGD to coasts. Numerous local studies show that the behavior of constituents in the subsurface (subterranean estuary) is not conservative. For example, geochemical transformations often challenge coastal hydrogeologists when defining groundwater "end-members". When summarizing data, our goal is to help the community to set clear guidelines and best sampling practices on such challenging aspects. This will ultimately result in more uniform data set that can be used by modelers on large scales.

Rationale

The overarching goal of this proposed SCOR working group is to set the guidelines and requirements for the development of global models for assessing constituent (nutrients, gases, carbon, metals) fluxes to the ocean via groundwater (NExT SGD). Current data availability (**Fig 1**) and conceptual understanding of the processes controlling groundwater-derived material fluxes is sufficient for formulating a numerical global model for assessing land–ocean material transport fluxes, similar to the river flux global model (GlobalNEWS) constructed about a decade ago (*Seitzinger and Harrison*, 2005). Indeed, the first global models of river constituent fluxes were developed based on a far smaller database than available for SGD today (e.g., *Gibbs and Kump, 1994).*

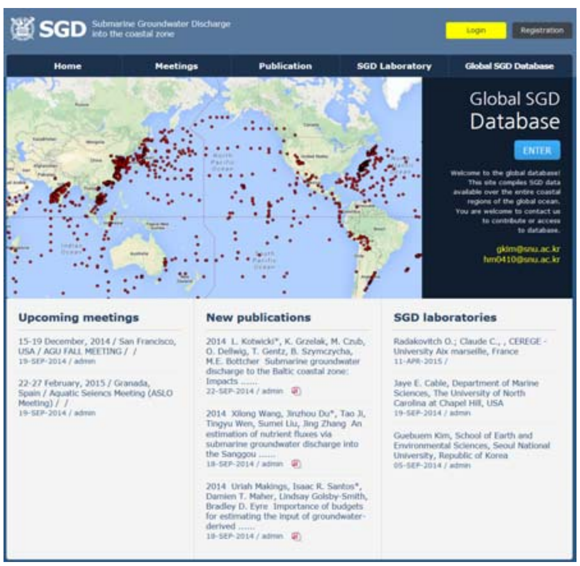

Figure 1 Snap-shot of a newly created web site by the working group to compile the available data (>100 locations worldwide presented as red dots). More data are available but not plotted on the map yet. (*from http://sgd.snu.ac.kr/home/gis_main.jsp*).

The global NExT SGD models will be based on the guidelines and metadata created by this working group, and will not only enable prediction of SGD-associated material fluxes for any location worldwide for present, past and future climate conditions, but also provide the tools to *test potential feedbacks* in the ocean-land-atmosphere earth system. Such a global model will transform our predictive abilities of this important, yet poorly constrained part of the hydrological cycle. Indeed, one of the pioneers in the SGD field advised that, "*The **oceanographic and hydrogeologic** communities should recognize the **local and global** importance of SGD and **work together** to achieve a better understanding of the processes that control SGD and its constituents*" (*Moore*, 2010).

The deliverables of these workshops will ensure that the models developed will be capable of capturing nutrient and flow changes triggered by short and long-term anthropogenic activities and climate, hence the models will allow the examination of various scenarios and their *ecological effects on ecosystems and economic effects on societies*. For example, excess nutrient loading due to SGD can initiate and sustain harmful algal blooms (HABs) in coastal areas (*Lee et al*., 2010, *Lecher et al.*, 2015). The predictive power of a large-scale model will allow the identification of locations susceptible to HABs triggered by SGD. Thus, the models developed based on the needs identified and database created from the results of this working group will not only significantly improve our understanding of the magnitude of groundwater-derived constituent budgets for the global coastal ocean, but will be extremely useful as a tool to highlight the need for water management assessments in some areas where no data are available.

We expect that the global NExT SGD models will enable us to *improve Earth System Models (ESMs)*, which at this stage neglect groundwater as a transport pathway from land to sea. For example, alkalinity supplied by groundwater may change the modeled pH response to increased atmospheric CO_2 concentrations (*Cyronak* et al. 2013). Given the potential importance of SGD for material fluxes into the ocean, its inclusion in the ESMs improve prediction accuracy of global change effects, including changes in sea-level on the oceans, and a global SGD model is a necessity to enable that inclusion. ESMs, like the ORCHIDEE model (http://orchidee.ipsl.jussieu.fr/) could easily be extended to include subsurface material fluxes by forcing existing parameters with outputs from the NExT SGD models.

Scientific Background

What is SGD and where does it occur? Submarine groundwater discharge (SGD) "*includes any and all flow of water on continental margins from the seabed to the coastal ocean, regardless of fluid composition or driving force*" (*Burnett et al.* 2003, *Moore* 2010) (**Fig. 2*a*,*b***).

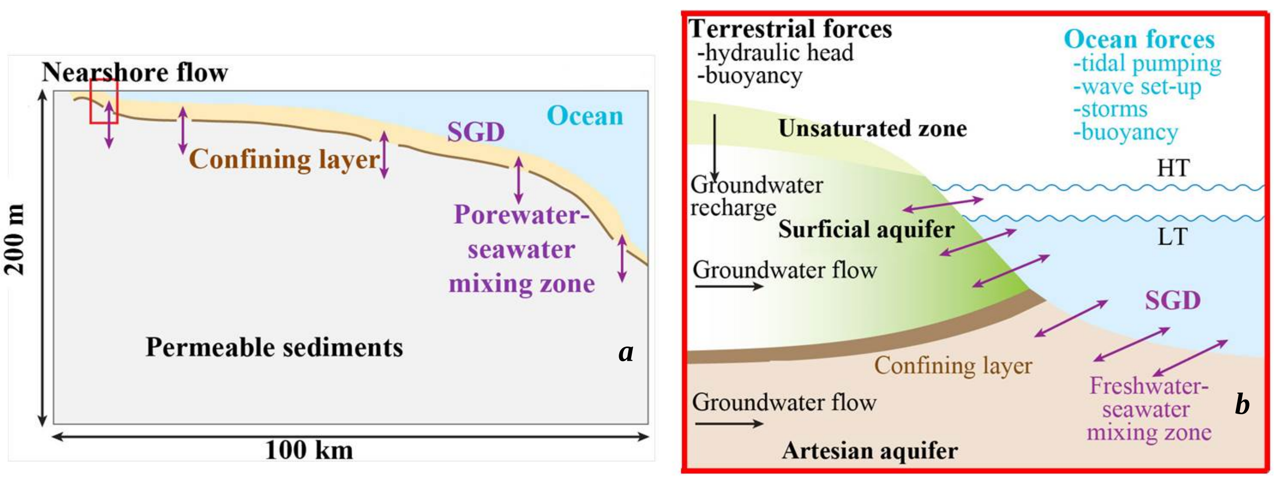

Figure 2 (***a***) SGD extends from the red box labeled "*Nearshore flow*" throughout the continental shelf. The offshore flow on the continual shelf is driven by interactions of ocean forces with geothermal heating and over-pressurized zones beneath discontinuous confining layers. ***(b)*** Near the shoreline SGD (red box) is driven by a combination of terrestrial and ocean physical forces operating in a complex geological environment (*modified from Moore, 2010*).

The outputs (including a database) of this working group will set the needs and guidelines to enable modeling of *nearshore fluxes (**Fig. 2b**)* of (*i*) fresh and (*ii*) recirculated seawater where most of the SGD data were collected and where most of the terrestrial groundwater-derived constituents are discharged (**Fig. 1**).

Despite the rich body of literature characterizing the transport of material fluxes via SGD to the nearshore environments at local scale (**Fig. 1**), to date attempts to upscale and evaluate water fluxes on regional or global scales are limited. In a recent study attempting global upscaling, *Kwon et al*. (2014) estimated SGD to amount to 3-4 times the river flux. However, the radium mass-balance approach used in this and other studies is not based on a mechanistic understanding of driving forces; hence its predictive and extrapolative abilities are limited. The *lack of a process-oriented model* is a very substantial knowledge gap, especially considering the links between ***SGD, the global carbon cycle, and climate change***. For example, in a key study, *Cole et al*. (2007) showed that SGD could contribute a similar amount of dissolved inorganic carbon (DIC) to the coastal ocean as rivers. *Beusen et al*. (2013) developed a global model for SGD-derived nitrogen fluxes, but neglected the marine recirculated SGD component, which often has a much larger volume than freshwater SGD and could contribute significantly to the magnitude of the material fluxes (e.g., *Burnett et al.*, 2003; *Waska & Kim* 2011). In all cases, the outcomes of these models were impeded by the limited understanding of either the coastal oceanographers of the specifics of the global modeling work or of the modelers about the nature of the collected data (i.e., mechanisms and geochemistry).

A multifaceted modeling approach based on recommendations from this workshop will be able to connect ***hydrogeological and marine factors*** (e.g., net precipitation, surface runoff, recharge, groundwater pumping rates, hydraulic heads, aquifer size and aquifer characteristics, topography, lithology, beach morphology, the presence and level of development of stream systems, waves, and tides) affecting SGD to ***nutrient and other constituents loading controls*** (e.g., land use, sewage and agriculture influxes, population growth, groundwater redox state and residence time) in coastal areas on a global scale. For most of the above-named controls, spatial data are available at very high resolution but there is a need to establish the controls on and sensitivity of SGD constituent fluxes to each of these processes to enable effectively incorporating into models. A similar approach was used by *Seitzinger and Harrison* (2005) to estimate export from ~6,000 watersheds globally. Results from these modeling efforts demonstrated the power of numerical models, which can be used not only *to create geospatial databases* of the magnitude of water fluxes but also *to reveal relationships* between controlling factors and drivers, which, in turn, transform our understanding about the coupled nature of these export fluxes at larger scales.

As emphasized before physical measurements from field-based studies are crucial for calibrating models and performing sensitivity analyses. Sufficient data are now available through the abundant SGD tracer-based coastal oceanographic studies of the last 20 years (**Fig. 1**) and the assimilation of many local studies in larger databases (e.g., *Moosdorf et al.*, 2015). However, the available SGD data is *highly heterogeneous*; it was produced by many different research groups and government agencies employing a multitude of measurement techniques and reporting standards. For these reasons, this extremely valuable information is currently practically unusable. Hence, the planned NExT SGD working group will set the guidelines for establishing an effective data compilation process that will facilitate data-use for models. Specifically, needs and guidelines for data compilation in a unified manner will be set. Equally important, the working group will also suggest best practices for future data collection. In addition, the parameters needed for the NExT SGD model development will be identified and assessed and model feasibility tested in a cutting-edge *proof-of-concept* study.

Terms of Reference

Disciplinary boundaries in the scientific community working at the land-ocean interface (i.e., oceanography community, hydrogeologists, and experts in global water flux modeling) have hindered the advancement of the mechanistic understanding of the significance of groundwater-derived nutrient fluxes to the ocean on a global scale. The NExT SGD workgroup recognizes SCOR as the perfect platform to encourage and stimulate the unique and timely collaboration between these disciplines. NExT SGD would build on the results of SCOR WG112 by collecting the observation data inspired by its results and adding the dimension of constituent fluxes to it.

The group's work will focus on the following terms of reference:

1. Collaborate with other working groups and projects (GEOTRACES, Global NEWS, BCO-DMO, etc.) to understand the needs and process for establishing a database useful for improving the representation of SGD in earth system models (e.g. ORCHIDEE) (*deliverable 1*, **Table 1**).

2. Produce a "*best practices*" technical note paper to be published in a peer reviewed journal recommending sampling strategies, parameter measurements, and guidelines for sample processing, metadata standards and sharing of acquired data (*deliverable 2*, **Table 1**).

3. Set the guidelines and expectation for establishing a permanent database of available SGD data including criteria for data quality control with the intention of this database to be usable for the planned NExT SGD Models. We will use these guidelines to request funds (NSF, EU) to establish and maintain such a database. (*deliverable 3*, **Table 1**).

We foresee the initiation and development of this unique collaboration proceeding in several stages (as shown **Table 1**) which will be centered on in-person meetings, and 2 out of 3 meetings held in conjunction with international conferences. We will organize a virtual seminar series (Webinar) to be delivered quarterly, by different members of the SCOR WG with focus on the progress of the data synthesis and analysis. At its completion, the recommendations will be distributed to the broader oceanographic community for input and feedback through established list servers (OCB, AGU, ASLO, etc.).

Working Plan and Deliverables

Constructing a global model to assess constituent fluxes via SGD is a pressing task. Our in-person meetings (as shown in **Table 1**) will be structured to address specific needs for model development necessary to establish the foundation for successful model outcomes. The groundwork for the NExT SGD models will be achieved through the following specific goals:

***Deliverable 1:* Set up a global network of scientists and SGD-"task force" across disciplines.**

The working group will bring together oceanographers, hydrologists, biogeochemists and modelers to discuss the needs and set the guidelines for the construction and incorporation of SGD water and nutrient fluxes into new or existing models. The group thus ensures information transfer both between the multidisciplinary participating members regarding the needs for the establishment of useful NExT SGD models. In particular, potential ecosystem feedbacks of SGD will be discussed, which have recently been highlighted in the literature (*Garcia-Orellana* et al, 20016*; Utsunomiya et al,* in press). Relevant factors for inclusion in the NExT SGD models will be identified by combining field knowledge of the submarine groundwater discharge community with factor needed for the setup of existing models (e.g. Global NEWS *Seitzinger and Harrison*, 2005). The unique combination of terrestrial and marine factors and their interplay is a special challenge to this working group. This will be reflected in the identification of model input data (e.g., land cover and population density, as well as tidal range and wave intensity). The planed meetings and interactions ensures the compatibility of the NExT SGD models with other global scale nutrient flux models and Earth System models, and the identification of gaps in data or model parameterization.

<u>Deliverable 2</u> Establish a handbook of best practices for sampling strategies, sample processing, and data handling and reporting for SGD data collection to be used in the NExT SGD models

SCOR working group 112 has established sampling techniques of SGD water flux which are used until today. However, these methods do not consider upscaling of SGD and associated constituent fluxes. Due to the large spatial and temporal variability of SGD fluxes and its constituent concentrations, we need to evaluate the currently applied techniques and formulate best practices for future fieldwork. This can be only archived if the two working bodies of the proposed working group, the scientists collecting actively the data and the global modelers, become engaged in interactive close-group meetings such as the SCOR ones. Past experience had proved that only through close personal interactions this international network of hydrogeologists and biogeochemists could compare, assess, and optimize *in situ* investigations of SGD magnitudes and associated constituent fluxes from local to regional scales and lay the foundation for a uniform comprehensive database to be utilized for building global material fluxes model (s). Furthermore, our working group will collaborate with the GEOTRACES community to plan for the collection of offshore SGD data and make sure it is compatible with the model requirements (http://www.geotraces.org/science/science-highlight/1019-submarine-groundwater-discharge-as-a-major-source-of-nutrients-in-the-mediterranean-sea). Based on the identified recommendations and model needs a best practice technical paper will be composed and disseminated broadly.

<u>Deliverable 3:</u> Establish recommendations to set up a database that will be used in the global NExT SGD models

The NExT SGD SCOR working group will develop specific technical guidelines in the form of *<u>metadata forms</u>* that will be embedded in the global SGD webpage (*from http://sgd.snu.ac.kr/home/gis_main.jsp)* and will be filled out for each site. We will discuss the requirements of a database and how to establish and maintain it. We envision a product in the form of a draft proposal for establishing a database that will be shared with the community for feedback and then developed into a proposal to obtain funding.

Establishing a database for SGD will ensure (*i*) *<u>quality control</u>* of the data to be used for the model; and (*ii*) the creation of a *<u>uniform record</u>* that will be independent of the field data collection and techniques.

The database will likely be stored in cooperation with a partner to ensure its permanent availability. As partners, the UNESCO IHP (which is represented in the group), the WHYMAP, or CUAHSI are envisioned. At the first group meeting the best fitting data host will be selected and afterwards contacted.

Table 1 Detailed timetable of the scientific activities, and expected deliverables of the working group

	Group activities and deliverables	Deadlines/meeting reports
Initial coordination and data management	1. Classifying sites into the 6 major domains based on aquifer type and dividing the working areas into several groups. 2. Developing specific technical guidelines for building a uniform metadata base of hydrogeological and nutrient parameters and topology. 3. Making initial decisions on governing parameters and boundary conditions for groundwater flow model. 4. Decide on data storage and data access.	SPRING: 2017 EGU Vienna (23–28 April 2017)
Global Model Development	1. Decisions on constituents adjustments and data gaps: a) Land coverage and use. b) Identifying sources and sinks of nutrients: natural (non-point-) versus anthropogenic (point-) sources. c) Climate change effects via sea level change and permafrost melting. 2. Refining decisions on scale constrains: upscaling/downscaling issues.	SPRING 2018: Ocean University of China, hosted by the Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Qingdao, China
Model Calibration	1. Further model parameterization and refinement. 2. Finalization of the SGD database V1.0 3. Working on dissemination of results in publications and meetings. 4. Writing and dissemination of the *best practices technical paper*.	FALL 2019: Final meeting December 2019 AGU Special session, San Francisco, USA

Capacity Building

Within the proposed group, we bring together global modeling experts from the riverine and groundwater modeling communities (e.g., Slomp, Cohen, Harrison, Michaels) with specialists in large database creation and management and holders of large SGD datasets (e.g., Kim, Moosdorf, Michaels) as well as field scientists for SGD from the terrestrial (Dimova, Cable, Santos) and marine (Dimova, Paytan, Burnett, Waska) realm. In addition to the broad scientific backgrounds, the proposed working group was assembled on the principle of geographical, economical (developed and countries in transition), gender and career stage diversity. The WG includes members from 14 countries spanning four continents with 40% female representation, and 30% members from developing and transition countries (**Tables 2 and 3**). Opportunity for broader involvement of the scientific community will be possible through open thematic sessions in large meetings and via open Webinars.

The uniqueness of this working group is its initiation largely by early-career young scientists, which has helped crossing traditional boundaries between the research fields of coastal oceanography, hydrology, and global numerical modeling. During the meeting planned in conjunction with the AGU Fall meeting in San Francisco 2019, we will hold a workshop in the form of a field trip as a training event for fellow interested scientists to expand their knowledge on the good practice of SGD measurement. However, in addition, we will expand this traditional outreach approach, by actively including social media via Facebook, Twitter, NExT SGD webpage Blogs, virtual seminars (Webinars) and crowdsourcing as part of our portfolio. Establishing the SCOR NExT SGD working group will foster further interdisciplinary collaboration and is intended catalyze new studies in areas where data gaps are identified during the compilation process. Developing this network will facilitate information exchange between scientists from developed countries and countries in transition. In most developing countries, nutrient enrichment of coastal waters due to SGD is unknown. Interactions among group members will create opportunities for student exchange and contribute to the enhancement of graduate programs in counties in transition. This, in turn, will promote wider public understanding of the effects of groundwater discharge. To optimize the educational effects, excursions will be held associated with the workgroup meetings. In particular at the last workshop at the AGU Fall meeting, a training excursion should transfer the developed knowledge from the project into practice.

Working group meetings will be organized on annual basis (as shown in **Table 1**). To allow broader participation, we plan to meet each year at different locations utilizing already established large international scientific meetings (e.g., EGU, AGU). The location of these meetings will rotate between the USA, Europe and Asia to distribute the cost of participation among group members.

We will seek funding from additional sources such as UNESCO, IAEA, LOICZ, as well as national and bi-national organizations (NSF, NERC, etc.). We will also establish a donation link on our web page to create an opportunity for private organizations to support our group. Funding through these alternative sources will be independent of that provided by SCOR.

Table 2 Full Members of the SCOR Working Group on Global Groundwater Fluxes to the Ocean

	Member	Gender	Place of work	Expertise relevant to proposal
1	Natasha Dimova (co-chair)	female	University of Alabama, USA	Radionuclides, coastal hydrology
2	Nils Moosdorf (co-chair)	male	Leibniz Center for Tropical Marine Ecology (ZMT), Bremen, Germany	Global empirical modeling
3	Guebuem Kim	male	Seoul National University, Korea	Radionuclides and nutrient cycling
4	Isaac Santos	male	Southern Cross University, Australia	Carbon cycling
5	Holly Michael	female	University of Delaware, USA	Numerical & field modeling of coastal groundwater dynamics
6	Caroline Slomp	female	Utrecht University, The Netherlands	Geochemical modeling
7	Makoto Taniguchi	male	Research Institute for Humanity and Nature, Japan	Regional and global groundwater hydrology
8	Bo Chao Xu	male	Ocean University of China	Coastal hydrology, geochemistry
9	Sara Purca	female	Institutto del mar del Peru (IMARPE)	Physical oceanography, fisheries, water resources
10.	Robert Delinom	male	Indonesian Institute of Sciences, Indonesia	Hydrogeology and geochemistry

Table 3 Associate Members of the SCOR Working Group on Global Groundwater Fluxes to the Ocean

	Member	Gender	Place of work	Expertise relevant to proposal
1	Hannelore Waska#	female	University of Oldenburg, Germany	Groundwater hydrology and geochemistry
2.	Adina Paytan#	female	UC Santa Cruz, USA	Biogeochemistry and nutrient cycling
3.	Jaye Cable	female	University of North Carolina, USA	Groundwater hydrogeology
4	Sagy Cohen	male	University of Alabama, USA	GIS, global numerical modeling, geomorphology
5	Kazi Matin Uddin Ahmed	male	University of Dhaka, Bangladesh	Groundwater contamination
6	Howard Waldron	male	University of Cape Town South Africa	Coastal zone water quality
7	Thomas Stieglitz	male	Centre for Tropical Water & Aquatic Ecosystem Research (James Cook University) Australia Centre de Recherche et d'Enseignement de Géosciences de l'Environnement CEREGE (European Centre for Teaching and Research In Geosciences) France	Geophysics and SGD
8	Yishai Weinstein	male	Bar-Ilan University, Israel	Hydrogelogy
9	Felipe Luis Niencheski	male	Fundação Universidade Federal do Rio Grande, Brazil	Environmental Chemistry
10	Alice Aurelie	female	UNESCO IHP, Paris	Hydrology

 # We would like to acknowledge specially HW and AP whose insightful comments were critical in preparation of this proposal.

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Appendix

Natasha Dimova (co-chair): Dr. Dimova is a coastal oceanographer and hydrogeologist with expertise in the radon-based tracer techniques in marine and freshwater systems. Dimova initiated the SCOR NExT SGD working group proposal and has been *working on compilation of SGD data* with Sagy Cohen (associate member) and Nils Moosdorf for establishing a global SGD model. She is an early-career female scientist who has been collaborating with scientists worldwide, including Asia, USA and Europe.

1) Dimova, N., Paytan, A., Kessler, J. D., Sparrow, K. J., Kodovska, F. G-T., Lecher, A., L., Murry, J., and Tulaczyk, S. (2015). Current magnitude and mechanisms of groundwater discharge in the Arctic: a case study from Alaska, *Environmental Science and Technology, DOI: 10.1021/acs.est.5b02215.*

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Nils Moosdorf (co-chair): Dr. Moosdorf is a hydrogeologist, specialized in estimating large scale geochemical material fluxes via statistical methods based on large datasets. His experience lays *in large scale river constituent flux modeling*. Since August 2014 he leads a junior research group on ecological impacts of SGD at different scales. He also specialized on global scale datasets based on lithological information. He is involved in several cooperative projects with scientists primarily in the USA, but also in Europe and Asia.

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Guebuem Kim: Dr. Kim's expertise is in radionuclides (Rn and Ra), organic matter, REE and *nutrient cycling in subterranean estuaries on a regional and global scale*. Dr. Kim established a webpage for SGD data compilation for initiating the NExT SGD working group.

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Isaac Santos: Dr. Santos was invited to be part of the NExT SGD working group because of the wide spectrum of research topics he has been involved with and his knowledge of the *carbon and* *nutrient cycling in subterranean estuaries*, specifically in carbonate sandy aquifers and coral reef environments.

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2) Santos, IR., B.D Eyre, and M. Huettel, 2012. The driving forces of porewater and groundwater flow in permeable coastal sediments: A review, *Estuarine, Coastal and Shelf Science* 98: 1-15

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Holly Michael: Dr. Michael was invited to this working group because of her unique expertise in both *numerical modeling and radio tracer field techniques*. Holly has established a connection between the two fields and plays an important role in breaking the boundaries between hydrogeology and coastal oceanography.

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Caroline Slomp: We invited Dr. Slomp as a full member because of her in-depth quantitative understanding of the cycling of elements in marine environments that will be essential in the mechanistic understanding of nutrient fluxes via SGD in nearshore coastal areas. Additionally, Dr. Slomp's research is broad in scope and involves field and laboratory work that is typically *integrated with large scale ocean and river modeling*.

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Makoto Taniguchi: Dr. Taniguchi has long-term experience in working on different aspects of groundwater and its significance for the global hydrological cycle. His contribution will be specifically in *connection between societies - water resources-climate change*. Dr. Taniguchi is also a former member of the SCOR 112 WG *Magnitude of Submarine Groundwater Discharge and its Influence on Coastal Oceanographic Processes***.** Dr. Taniguchi is also a member of the IAPSO Commission on Groundwater Seawater Interactions whose results we should build on.

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Bo-chao Xu: The contribution of Dr. Xu for this working group will be primarily in his understanding of *SGD impacts on large estuaries* and the geochemical transformations of nutrients at the sediment-water interface.

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Sara Purca: Dr. Purca is an *oceanographer* whose research focus is in coastal water management and biological (fisheries) modeling. Her extended experience in coastal hydrodynamics along the Peruvian coastline will fill the gap of "*volcanic aquifers*" and the effects of upwelling to quality of coastal waters.

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Robert Delinom: Prof. Delinom is *hydrogeologist* who leads a working group which researched submarine groundwater discharge on different Indonesian islands. His perspective will highlight the *tropical regions*, where particularly tropical islands can contribute significantly to global fluxes and show strong local impacts of SGD.

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Proposal for a SCOR Working Group

Title: The dynamic ecogeomorphic evolution of mangrove and salt marsh coastlines

Acronym: DEMASCO

Summary/Abstract

The goal of this working group is to unravel the interdisciplinary feedbacks between physical and ecological processes, and to develop a robust framework to understand and manage the future of vegetated shorelines. The world's coastlines are highly dynamic regions subject to oceanic energy in the form of waves, tides and storm surge. Marine vegetation like tidal marshes and mangroves have been shown to provide defense against these often-destructive forces while simultaneously providing ecological co-benefits, such as providing critical habitat for economically-valuable flora and fauna and serving a vital role in the sequestration of blue carbon. All of these roles are threatened by the predicted impacts of climate change, such as sea level rise and increased storminess, in addition to reduced resilience owing to anthropogenic developments, such as reservoir and dam construction. However, the complex biophysical feedbacks between sediment, hydrodynamics and vegetation are still not well understood, and these gaps in knowledge limit our ability to successfully apply ecosystem-based management of highly populated and high risk low lying coastal regions. This proposed working group includes members spanning the globe and encompassing the many different areas of expertise required to make significant jumps forward in this interdisciplinary space. The group aims to meet yearly for three years and produce two peer-reviewed scientific reviews (one focused on physical processes and one on management) and an applied report for managers and policy-makers, in addition to keeping the wider community involved through development of a website and the proposal to organize an AGU Chapman Conference.

Scientific Background and Rationale

Rationale

A growing amount of attention and research has focused on the roles that marsh or mangrove vegetation plays in estuaries. From an ecological perspective, coastal vegetation supports functions that are critical to numerous ecosystem services and the economic value of this natural capital is being increasingly recognized (Costanza *et al.*, 1997, Barbier et al., 2008). Furthermore, coastal wetlands have been shown to play a substantial role in blue carbon storage. Both tidal marshes and mangrove swamps possess the ability to sequester disproportionately large quantities of CO_2, with a burial capacity, which is estimated at six times that of the Amazonian rainforest and 180 times that of the open ocean (Nelleman et al., 2009; Donato et al., 2011; McLeod et al., 2011; Breithaupt et al., 2012). Lastly, in addition to providing ecosystem services, attention in recent years has focused on the ability of coastal wetlands to provide protection, buffering shorelines against damage (Arkema *et al.*, 2013; Temmerman *et al.*, 2013), even during extreme conditions such as large wave events (Möller *et al.*, 2014) or tsunamis (Wolanski, 2007).

There is growing acknowledgement of the enhanced vulnerability of coastlines in the face of global climate change, with some areas predicted to encounter more frequent and stronger extreme storm events (e.g. Webster *et al.*, 2005; Knutson *et al.*, 2010), while other areas face significant sea level rise (Sallenger *et al.*, 2012). Moreover, anthropogenic activities are reducing sediment supply to the coast, resulting in reduced accretionary capacity and hence, reduced resilience of these valuable ecosystems. The use of 'ecodefense', or protecting coastlines through nature offers a cost effective alternative to traditional hard structures, which often are accompanied by negative effects such as fragmenting habitats and reducing ecological connectivity (Peterson and Lowe, 2009). Conversely, 'soft' solutions can enhance resilience, improve water quality and provide habitat for biodiversity offsetting (Jones et al., 2012). However, habitat creation has achieved differing degrees of success and improved understanding of the underlying biophysical processes is necessary in order to raise the success of these remediation measures. This vulnerability, coupled with the recent disappearance and accelerating rate of decline of estuarine wetlands and mangroves (Duke, 2007; IPCC, 2013), has brought the topic to the forefront of coastal science.

Substantial progress has been made in the area of the interaction between vegetation and flow, at small (Nepf 2012a, 2012b) and large scales (D'Alpaos *et al.*, 2007; Fagherazzi *et al.*, 2012, Coco *et al.,* 2013; Zhou *et al.,* 2014). However, many large challenges persist. At the small scale, much previous work has been conducted in laboratory flumes using mimics or plants with approximately uniform or simplified morphologies. It remains an open question of how to best scale these results to incorporate the huge range of heterogeneity of bathymetry, densities and vegetation characteristics (e.g. stiffness, lengths etc.) observed within even one marsh area (Bouma *et al.*, 2007). One way forward is to develop hydrodynamic models that include vegetation dynamics, and indeed some modeling packages have incorporated flow over vegetation (e.g. Delft3d, Baptist *et al.*, 2007). Further work is needed on how to parameterize and integrate plant growth models (e.g. incorporating effects such as seasonal die back). Vegetation has been observed to both enhance erosion, particularly through scouring at marsh edges, but to also enhance sediment deposition through damping of energy. The precise balance between these two processes and feedbacks with plant growth, particularly on the larger scales from multiple patches to entire marsh scales only begins to be addressed (Marani *et al.*, 2010). Other biota can also modulate these processes through bioturbation and biostabilisation. Combining all of these processes over long-time scales, covering both extreme and normal conditions is a significant challenge (Bouma *et al.*, 2014). Even after these scientific challenges have been addressed, there remains the significant challenge of connecting the existing and future scientific knowledge with societal values, which can then be translated into policy (Wolanski and Elliot, 2016).

Given the broad scope and interdisciplinary nature of these challenges and the relevance for policy-making and management of estuaries, we propose that the research area is ideally suited to being tackled by a SCOR working group. This working group would provide opportunities to bring together specialists whose work encompasses a range of scales, skills and processes. The group would bring together the mangrove and saltmarsh communities and also combine laboratory experimentalists, field-based scientists, and numerical modelers and scientists heavily involved with policy-making and assessment frameworks. Now is an excellent time to make progress on the key questions especially in light of new instrumentation allowing high-resolution measurements (Mullarney *et al.*, 2015) and improved remote sensing techniques (Silvestri and Marani, 2004). The working group proposed here will be focused on saltmarshes and mangroves, because they represent the most common intertidal vegetated habitats from temperate to tropical climates. However, it is envisioned that the wider community would also be integrated through the proposed Chapman Conference on the broader topic of vegetation ecohydrodynamics.

The working group would provide assistance to integrate scientists from developing countries, who sometimes lack resources to attend international meetings. This involvement is crucial, noting that it is often in these regions that salt marsh and mangrove areas are being destroyed at the fastest rates (e.g. Vietnam, Thu and Populus, 2007).

Scientific Background

The presence of vegetation introduces significant spatial variation to flow, much of which is associated with the heterogeneity of natural canopies. Within a plant canopy, the key length scales are defined by the stem diameter and stem spacing (Figure 1). This change of scale results in damping of larger scale motions, but introduces turbulence (through vortex shedding) at the smaller stem scale. Inside a canopy, the bulk canopy drag increases with the density of vegetation. This additional drag reduces mean flow speeds and turbulence intensities with distance from the seaward marsh edge (Leonard and Luther, 1995) or can cause flow routing around areas of higher densities. Vegetation can also induce mechanical lateral and longitudinal dispersion owing to particles becoming caught in eddies behind stems.

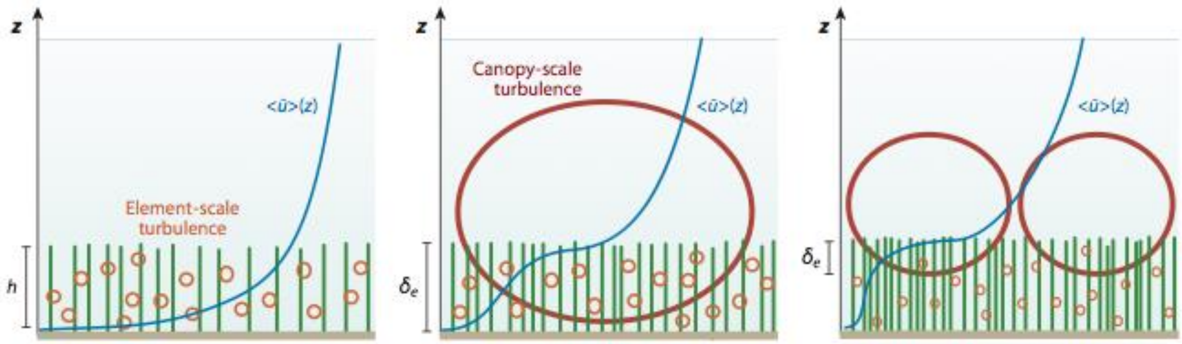

Figure 1: Schematic showing the change in velocity profiles and length scales associated with the presence of vegetation from sparse (left) to transitional (middle) to dense (right) submerged canopies. For the dense vegetation, shear at the top of the canopy induces monami (or waving) and canopy scale turbulence. Figure from Nepf (2012a).

Both laboratory and field studies have demonstrated that saltmarsh vegetation and mangroves are capable of dissipating wave energy. Indeed, salt marshes have been shown to effectively dissipate waves even during larger wave events and high water levels (Möller *et al.*, 2014). However, the extent of this dissipation is frequency dependent and also depends strongly on the vegetation characteristics (Mullarney and Henderson, 2010).

The tendency for vegetation to slow currents and dissipate waves can create sheltered regions of low flow, where sediments can deposit and marshes typically experience enhanced deposition (Coco *et al.*, 2013). However, recent measurements have demonstrated scour around stems at the marsh edge and the precise balance between the erosional and accretional processes is not yet clear (Tinoco and Coco, 2013). Despite these differences in observed sedimentation between studies, it is generally acknowledged that the three-dimensional structure of the vegetation is an important factor influencing sedimentation patterns within a salt marsh. Hence the vegetation, in part, controls the longer-term marsh scale evolution. However, as noted by Fagherazzi *et al.* (2012), many recent process based models are developed for specific locations and individual species and the wider-applicability of these models is not yet known. A working group would provide an excellent opportunity to answer some of these questions at this critical time.

Terms of Reference

The goals of this working group are as follows:

- Synthesize current knowledge of salt marsh and mangrove swamp evolution, focussing on the key processes (and similarities and differences between the two systems) in two open-access review articles, one focused on the physical processes (possible journals – Reviews of Geophysics, Estuarine Coastal and Shelf Science, Advances in Water Research) and a second focused on management (possible journals - Conservation Letters, Ecological Engineering, Restoration Ecology). The articles will identify key gaps in understanding and make recommendations for collaborative future research directions. Particular attention will focus on growth and disappearance of marshes, ecosystem services such as wave attenuation, importance for birds/fisheries and carbon sequestration.

- Facilitate collaboration between observational and numerical modeling studies of saltmarsh and mangrove systems. In particular, we aim to:
    - Promote the migration of existing data sets into numerical models
    - Select benchmark dataset(s) that can be used to parameterize and validate numerical models.
    - Identification of existing models and discussion on their strengths and weaknesses.

- Produce a short article for policymakers on how a knowledge of ecogeomorphic evolution could contribute to better management and restoration of salt marshes and mangrove systems. It is envisaged that this article will contain a 'salt marshes for dummies' section on the physics, chemistry and biology of these ecosystems, describing the key processes from a long-term perspective, and a section that quantifies the ecosystem services (benefits) of these systems that includes several case-studies/lessons learned.

- Write a proposal for a 2019 AGU Chapman Conference on the wider topic of vegetation ecohydrodynamics.

Working plan (logical sequence of steps to fulfill terms of reference, with timeline. Max. 1000 words)

Our first working group meeting will be held in 2017 (likely at the international conference River, Coastal and Estuarine Morphodynamics). This meeting will focus on the following:

- Reviewing the terms of reference and adjusting them as necessary.
- Formulating a concrete action plan for the group.
- Review the state of knowledge and identify critical gaps.
- Discussion of existing data sets. Identify which are best suited for use by modeling community and strategies to make these datasets available.
- In light of the above, compiling components of the review article.
- Discussion and identification of potential sources for further funding.

The second meeting will be held in 2018 (likely at the AGU Ocean Sciences meeting) and efforts will be concentrated on the following:

- Final discussion on the review articles with an aim to submitting shortly after the meeting.
- Initial discussions on a Chapman conference – identifying key participants (i.e conveners).
- Outlining report for policy makers and managers. Discussion on the best strategy for production.
- Ensure the website is up and running

The third meeting should be held in 2019 (possibly in conjunction with the Estuarine, Coastal Sciences Association Conference) and involve:

- Final discussion on applied report. Dissemination shortly afterwards.
- Prepare a final report outlining progress made and future directions of research.
- Continued organization for the Chapman Conference, which should be held before the end of the year.

Deliverables (state clearly what products the WG will generate. Should relate to the terms of reference. Max 250 words). A workshop is not a deliverable. Please note that SCOR prefers that publications be in open-access journals.

The group will strive to produce the following outputs:

1. A final report detailing the work of the group, including results of discussions on the identification of key knowledge gaps to guide future research.
2. An article designed for policy makers on the management and restoration of salt marsh and mangrove ecosystems.
3. An up-to-date website of the group's activities.
4. Two review papers (one focusing on physical processes and the other on management) in a peer-reviewed open access international journal.
5. A proposal for an American Geophysical Union Chapman Conference

Capacity Building (How will this WG build long-lasting capacity for practicing and understanding this area of marine science globally. Max 500 words)

With members spanning the 5 continents, our proposed group will help to build scientific capacity globally. In particular, we hope to build scientific capacity in Africa, Vietnam, and South America. As noted above, many developing regions are threatened by the conversion of wetland and mangrove areas; and by improving capacity in these countries, we hope to raise awareness of the ecological and economic values of these ecosystems. We will also seek advice from the SCOR committee on capacity building on how our working group can further enhance scientific development around the globe. Many members are associated with a range of international programs and this working group will enable all members to widen their professional networks. If successful, we will liaise with advocacy groups, the mangrove action project and wetlands international, to discuss the best course of action to disseminate the work of the group.

We also will invite early career scientists from developing countries to participate in the second working group meeting (including providing advice on applying for visiting scholars programs and travel grants).

Working Group composition (as table). Divide by Full Members (10 people) and Associate Members, taking note of scientific discipline spread, geographical spread, and gender balance. (max. 500 words)

Our proposed group has three co-chairs – Julia Mullarney, Iris Möller and Eric Wolanski. We have selected a chair covering all career stages and from both hemispheres. Each chair will take responsibility for a key deliverable and organizing one meeting (Mullarney will also take on the responsibility of organizing the first meeting and will be the overall point of contact for SCOR).

Our proposed working group contains 10 full members and 10 associate members, representing a balance of geographic locations, interdisciplinary expertise, seniority (all career stages are involved) and gender (see table). Given a large focus of the group is the parameterization of key processes for inclusion into numerical models; we have two members strongly linked to Delft Hydraulics (one associate and one full member). We have ensured membership encompasses scientists bringing together all currently available tools such as field observationalists, laboratory experimentalists, numerical modelers and members with expertise in remote sensing. Additionally, given one of the aims of the group is to bridge the gap between science and policy, we have several members with expertise in coastal policy; ecosystem based management, biodiversity offsetting, and integrated assessment frameworks. We are also currently exploring options for co-funding and support from other organizations such as LOICZ and the United Nations Environment Programme and are currently awaiting responses to our initial inquiries. We note that several other scientists have expressed interest in collaborating with the group in an informal capacity.

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

Name	Gender	Place of work	Expertise relevant to proposal	Career Stage
1 Julia Mullarney Co-chair	Female	University of Waikato, New Zealand	Small scale turbulence inside canopies/vegetation movement	J/I
2 Eric Wolanski Co-chair	Male	James Cook University, Australia	Estuarine ecohydrology	S
3 Iris Möller Co-chair	Female	University of Cambridge, England	Bio-physical interactions in salt marsh systems and their significance for decadal scale marsh stability, wetland science communication and stakeholder involvement	I
4 Hong-Phuoc Vo-Luong	Female	National University of Science, Ho Chi Minh City, Vietnam	Flows and sedimentation within mangroves	I
5 Tjeerd Bouma	Male	Royal Netherlands Institute of Sea	Spatial ecology, conservation ecology,	S

		Research (NIOZ), the Netherlands	nature based coastal defense	
6 Jasper Dijkstra	Male	Deltares, The Netherlands	Numerical modeling of vegetated regions	J/I
7 Heidi Nepf	Female	Massachusetts Institute of Technology, USA	Vegetated hydrodynamics and morphodynamics	S
8 Gerardo Perillo	Male	Argentinian Institute of Oceanography, Bahia Blanca, Argentina	Oceanography, physical-biological interactions, sediment transport	S
9 Julius Agboola	Male	University of Lagos, Akoka, Nigeria	Land-ocean interaction, coastal biogeochemistry, environmental change	J/I
10 Zeng Zhou	Male	Hohai University, Nanjing, China	Ecomorphodynamics	J

Associate Member (no more than 10)

Name	Gender	Place of work	Expertise relevant to proposal	Career Stage
1 Fernando Mendez	Male	University of Cantabria, Spain	Climate and waves, extremes, coastal climate change	I
2 Andrea D'Alpaos	Male	University of Padova, Italy	Ecomorphodynamics	S
3 Dano Roelvink	Male	UNESCO-IHE, The Netherlands	Morphodynamic numerical modeling	S
4 Sergio Fagherazzi	Male	Boston University, USA	Geomorphic evolution of salt marshes/remote sensing of vegetated regions	I/S
5 Giovanni Coco	Male	University of Auckland, New Zealand	Geomorphology and biophysical interactions	I/S
6 Alice Newton	Female	University of Algarve, Portugal and Norwegian Institute of Air Research,	Coastal lagoons, integrated assessment frameworks (SAF and DPSIR)	S
7 Gail Chmura	Female	McGill University, Canada	Carbon fluxes and impacts of nutrient enrichment	S
8 Chen Wang	Female	Satellite Environment Center of the Ministry of Environmental Protection, China	Remote sensing/satellite imaging and GIS of coastal wetlands	J
9 Mike Elliott	Male	University of Hull, UK	Effects of human activities on biological systems, coastal policy, biodiversity offsetting	S

10 Marco Marani	Male	Duke University, USA	Observations and modeling interactions between vegetation species, erosion/deposition, intertidal landforms, and biodiversity	S

Working Group contributions (max. 500 words)
Detail for each Full Member (max. 2 sentences per member) why she/he is being proposed as a Full Member of the Working Group, what is her/his unique contribution?

The working group has been designed to bring together people with complementary primary areas of expertise. Mullarney focuses on smaller-scale observation measurements within vegetated environments and the movement of vegetation under hydrodynamic forcing. Wolanski is a leading expert in the areas of coastal oceanography and ecohydraulics. Vo-Luong's research focuses on flows and sediment transport within mangrove forests, and she takes a field and theoretical approach. Nepf is a world expert in flows within vegetated canopies, with particular emphasis on laboratory experiments. Bouma is a spatial ecologist with key research areas of ecological restoration and plants as ecosystem engineers. Dijkstra specializes in numerical modeling of vegetated regions (and salt marshes in particular). Perillo's research combines oceanography, hydrology and geomorphology; Zhou has recently completed a novel model that addresses feedbacks between marshes, physical processes and carbon dynamics. Agboola has experience in land-ocean Interaction in addition to coastal biogeochemistry and ecosystem management. Möller is a coastal geomorphologist with a research focus on the linkage between short term (event-based) plant-wave interaction and its significance for decadal scale coastal wetland evolution in the face of climate changed induced alterations to storm frequency and magnitude. More recently Möller has also been actively involved in addressing the communication gap between the academic community and stakeholders involved in coastal management.

Relationship to other international programs and SCOR Working groups (max. 500 words)

Many working group members have substantial linkages to other international programs and have been involved in successful SCOR working groups in the past (Wolanski, Perillo and Elliott). Mullarney and Vo-Luong (full members) and Fagherazzi and Roelvink (associate) are participants in the USA Office of Naval Research funded departmental research initiative "Dynamics of tropical deltas" studying flows and sediment transport in the Mekong Delta.

Key References (max. 500 words)

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Appendix

For each Full Member, indicate 5 key publications related to the proposal.

Julia Mullarney

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Eric Wolanski

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Title:
Towards strategic observatories for regional ocean-atmosphere interactions in the Eastern Boundary Upwelling Systems

Acronym: cOCtEAU (OCEan Atmosphere Upwelling)

Summary/Abstract

Eastern Boundary Upwelling Systems (EBUS) (California, Peru-Chile, Benguela and Canary Current, Sumatra-Java System) are characterized by complex dynamical processes spanning a wide range of spatio-temporal variability due to the strong coupling between atmosphere, ocean and land. They are the most productive marine ecosystems in the world supporting some of the world's major fisheries, being key socio-economic sectors for southern countries and supply of marine products worldwide. At the eastern boundaries of ocean basins, trade winds blowing equatorward produce coastal upwelling, which uplifts cold and nutrient-rich waters toward the surface, where favorable light conditions sustain phytoplankton growth. The air-sea-land processes in these regions also span a wide range of characteristics and nature, and their role in modulating the upwelling dynamics and productivity is presently unclear. Moreover, remote forcing can influence upwelling at timescales from intraseasonal to interdecadal and longer. Below the surface ocean, intense Oxygen Minimum Zones develop due to high organic matter export leading to production and release of climatically-active gases (CO_2, N_2O) and trace gases to the atmosphere. EBUS are also characterized by strong submeso- and mesoscale variability that links the coastal system to the open ocean. This SCOR WG is aimed at increasing the scientific understanding of the interactive processes between land, ocean and atmosphere and their impacts on the marine biogeochemistry and ecosystems at the regional scale. It will focus on the integration of existing knowledge from *in situ* and satellite observations and modeling approaches and formulate a **strategic recommendation white paper** for setting up observational programs/platforms (i.e. OceanSITES) that will fill in the gaps in our understanding of physical and biogeochemical ocean-atmosphere interactions in these regions.

Scientific Background and Rationale

The Eastern Boundary Upwelling Systems (EBUS) are widely known to be the most productive areas of the world's oceans (Pauly and Christensen, 1995), supporting large populations of commercially important fish species (Bakun et al., 2015). This is mainly driven by the air-sea interaction which is triggered when the equatorward alongshore wind displaces the surface layers of the ocean and, by mass conservation, cold, nutrient-rich deeper waters outcrop to re-establish the geostrophic equilibrium in eastern boundaries, developing the so-called Coastal Upwelling Systems. These areas (California, Peru-Chile, Benguela and Canary Current, Sumatra-Java Systems) are characterized by alongshore boundary currents, filaments, squirts, mesoscale eddies and internal waves, which are also driven, triggered and modulated by the local-to-regional wind response (e.g., Chelton et al., 2007). These processes interact at different timescales, thus enriching the coastal upwelling dynamics and defining the oceanography of these regions. The combination of sluggish circulation and high biological productivity in the surface layer drives elevated rates of organic matter decomposition and dissolved oxygen consumption, resulting in the development of the Oxygen Minimum Zones (OMZs). Low-oxygen areas are important for macroorganisms that cannot survive in oxygen-poor conditions. Extreme anoxic events can have serious impacts either through the habitat structuration or reduction (for instance the Humboldt with a shallow habitable layer which has consequences on catchability) or on mortality (rock-lobster walkouts in the Benguela are well documented). Peculiar biogeochemical processes also occur at low oxygen concentrations that influence global ocean nutrient cycles as well as production of greenhouse gases (e.g. Stramma et al., 2010). The impact of oceanic trace gases on atmospheric chemistry is also yet to be determined.

The basic forcing mechanisms are similar across the different EBUS and establish similarities in essential physical dynamics and ecosystem structure, and progress has been achieved in understanding the EBUS dynamics from an integrative and comparative perspective (e.g., Pegliasco et al., 2015; Capet et al., 2014; Lackar and Gruber, 2012; Gruber et al. 2011; Chavez and Messié, 2009; Capet et al., 2008; Carr and Kearns, 2003). However, many questions still remain regarding specific processes associated with individual EBUS (e.g. the strength of the equatorial teleconnection) and their sensitivity to climate change (e.g. Wang et al., 2015; Bakun et al., 2015; Mackas et al., 2006). For instance, the Peruvian sector of the Humboldt system is one of the most productive EBUS, yet it experiences the largest fluctuations at interannual timescales (i.e., El Niño) compared to the other EBUS systems. The EBUS in the Indian Ocean, the Sumatra-Java upwelling system is relatively less studied, although it plays an important role in the development of the Indian Ocean Dipole (Saji et al., 1999). The difference in their latitudinal positions (Figure 1) implies that some EBUS or EBUS sub-components are more wind-driven (those at high-latitudes) while others experience more tropical oceanic teleconnections, although the Benguela EBUS is also influenced by the Agulhas leakage. Therefore while commonalities in the nature of the forcing have suggested that a common theory of the circulation and its role on biogeochemical properties (e.g. OMZs) could be drawn, the current characteristics of the forcing (amplitude, frequency, persistence, asymmetry) linked to inherent non-linearities of the systems call for revisiting this paradigm. Progress in regional modeling has shed light on potentially important processes that were only inferred until recently (e.g. effect of the wind-drop off on upwelling dynamics (e.g. Capet et al., 2004); current-wind coupling (Chelton et al., 2007); eddies-induced transport (Bettencourt et al., 2015; Gruber et al., 2011; Rossi et al., 2008)) and that are difficult to tackle only with observations. While most modeling studies have been process-oriented, some long-term regional hindcast simulations are becoming available, allowing investigation of low-frequency time scales and estimations of the importance of different regional feedbacks within a climate framework. It is also of interest to contrast the EBUS with the weak upwelling/less productive eastern boundary current systems such as the Iberian Current and Leeuwin Current systems, so as to better understand possible evolution of the EBUS under the future climate change.

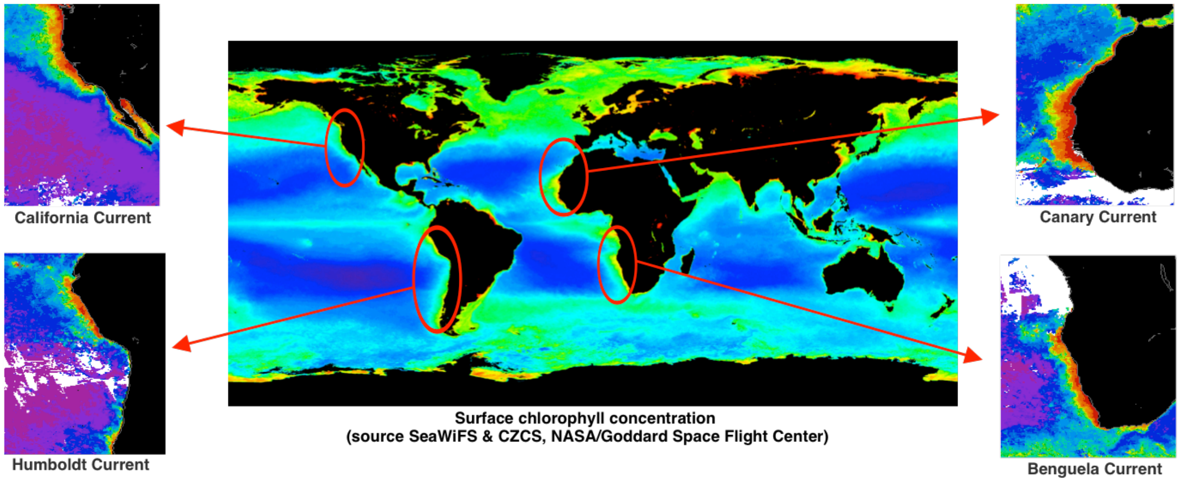

Figure 1. Distribution of Eastern Boundary Upwelling Systems and global satellite-derived annual average chlorophyll-a concentration.

This has spurred in recent years a number of individual efforts to understand the EBUS dynamics from an observational perspective, e.g., the international CLIVAR program VOCALS (VAMOS Ocean-Cloud-Atmosphere-Land Study) implemented to develop and promote scientific activities leading to an improved understanding of the South Eastern Pacific coupled ocean-atmosphere-land system on diurnal to interannual timescales. The transdisciplinary AMOP (Activities of research dedicated to the Minimum of Oxygen in the eastern Pacific) project was launched to investigate the mechanisms leading to the formation of the OMZ existence off Peru and its variability from hourly to centennial timescales. The German initiative SFB754 'Climate-Biogeochemistry Interactions in the tropical Ocean' addressed the relatively newly recognized threat of ocean deoxygenation, its possible impact on tropical OMZs and implications for the global climate-biogeochemistry system. However, the problem of undersampling, the inadequacy of our current mode of ocean observations to cover the relevant spatial and temporal scales, is still significant despite progress in both observational platforms (gliders, wavegliders, ARGO floats, AUVs, aerial drones) and autonomous physical and biogeochemical sensors, as well as remote sensing. Likewise, the available global models, while useful to document climate variability and its sensitivity to mean state change, still exhibit severe biases at regional scales, in particular in EBUS (in Sea Surface Temperature, Richter, 2015) and OMZs structure (Cabré et al., 2015). Thus, regional models have been used showing an adequate reproduction of the known aspects of the regional dynamics and are useful to elucidate key questions, e.g., the dynamical relationship between the ocean circulation and OMZs (Montes et al., 2014) that, certainly due to scarce spatial and temporal data distribution, would have been difficult to detect with observations. However, most published modeling work addressing EBUS variability comprises process-studies at short or climatological timescales.

In brief, there are a number of regional processes in EBUS that modelling studies suggest are important but that have been undocumented by observations. This calls for more quantitative evaluations of the role of such processes in EBUS dynamics from integrated modeling platforms, i.e., that take into account the complex feedbacks and scale interactions, and operate within a climate perspective, i.e., from long-term (multidecadal) simulations. The socio-economic importance of EBUS (1% of global ocean area that sustains 20% of the world's fish catch) further motivates to investigate the role of these regional air-sea interactions onto the biogeochemistry of the OMZs in order to improve our predictive capabilities of the evolution of the marine ecosystems in these key economic regions. This will require efficient observing systems, and via this proposed working group we aim to provide guidance for the design of observational strategy that will specifically improve our process understanding of the dynamical EBUS regions.

The cOCtEAU WG will address the knowledge gaps outlined above by making recommendations as to how better and more cost-efficiently observe these regions in both the ocean and atmosphere *simultaneously*. It will first provide a comprehensive evaluation of current knowledge regarding control mechanisms, impacts on biogeochemical cycles and feedbacks derived from all published observational and modeling approaches, and will then develop a strategical recommendation white paper to fill the gaps. To achieve this goal, a unique mixed group of early career scientists - with an appropriate gender balance - and more senior scientists, all experts in different EBUS of the world ocean, from observational and modelling perspectives, and originating from various developed and developing countries and disciplines, has been invited to participate in this working group.

Terms of Reference

1. **Synthesize** the existing knowledge about the different physical and biogeochemical mechanisms occurring over different time scales (i.e., intradaily, intraseasonal, interannual, decadal, multidecadal) and their influence on water column properties, biogeochemical cycles, biodiversity/ecosystem structure and functioning and regional climate, to identify the key feedback processes and establish the knowledge gaps. The **first workshop** will focus on organizing the **peer-reviewed publication** of this synthesis to be published in an open-access journal.

2. **Develop a compendium** containing a compilation of regional observational systems (e.g., available period, papers published, associated database) and numerical simulations (e.g., including configurations details, scientific production, responsible scientists and their contacts); being prepared as online newsletter for the oceanic and atmospheric science community (especially PhD students and early career scientists).

3. **Produce a** comparative analysis from modelling validated/published results, presented as a **high impact factor review paper**. Terms of References 2-3 will be the target of a **workshop**, followed by **a summer school** organized either in Senegal or Peru involving PhD students and early career scientists mostly from Africa and South America.

4. **Provide a strategic recommendation white paper** for setting up regional observational systems to monitor and understand physical and biogeochemical ocean-atmosphere interactions. These observational systems will be instrumental in improving the performance and reliability of climate models in these socio-

economically relevant regions of the world ocean. Additionally, **a conference** with decision makers, stakeholders and the scientific community will be organized to present the main findings, suggest priority topics and offer alternatives to approach solutions.

Working plan

Year 1

- **cOCtEAU First Workshop**. Objective 'Organize the structure of the peer-reviewed publication synthesizing the existing knowledge on EBUS'. Full and associate members will attend together with their PhD students (at least one each). This workshop will be held potentially in combination with the AGU Fall Meeting.
- **Submit the peer-reviewed publication** wherein a synthesis of the existing knowledge (physical and biogeochemical ocean and atmosphere components and ocean-atmosphere interactions) on EBUS is presented.

Year 2

- **One day cOCtEAU Second Workshop.** Objective: 'Organize the **compendium** and the **high impact factor review paper'. The compendium** will provide a detailed list of regional observational systems and numerical simulations both in the ocean and atmosphere and, this will serve as material to produce the **high impact factor review paper** that will provide a comparative analysis from modelling results. Full and associate members will attend. This workshop will be held potentially in conjunction with AGU Fall Meeting.
- **Release the compendium** of the compilation of regional observational systems and numerical simulations.
- **cOCtEAU Summer School**. Objective: 'Present an overview of the main EBUS processes, teach the necessary topics required to understand ocean-atmosphere interactions, combine lectures and hands-on sessions, practical lessons'. All experts and younger scientists will participate by giving lectures and tutorials.
- **Submit the high impact factor review paper compiling modelling results** as a comparison to establish strengths and weaknesses of regional modelling simulations. This will help to point out considerations/actions to be taken in global models as well as observational platforms for better understanding of EBUS dynamics.

Year 3

- **cOCtEAU Open Science Conference**
  Day 1: Objective 'Organize the strategical recommendation brief to be presented as a short paper to the Executive Panel'.
  Days 2-3: Objective 'Bring together all interdisciplinary and multidisciplinary ocean and atmospheric science communities involving modelers and observationalists studying EBUS and related topics'.
  Day 4: **Executive Panel.** Objective 'Bring together decision makers, stakeholders and the scientific community to present and highlight the main findings, suggest first priority topics, offer suitable and cost-effective alternatives to approach

solutions to further understand the EBUS dynamics'. It will be developed just after **cOCtEAU Open Science Conference**.

- **Submit the white paper** wherein the strategic recommendation brief is presented.
- **Final Report** of the whole SCOR WG.

Deliverables

Deliverable 1. **A peer-reviewed publication**, wherein the existing knowledge about the different physical and biogeochemical mechanisms developed over different time scales on EBUS is synthesized. This paper will cover three aspects: (1) a theoretical aspect, in terms of theoretical processes, synthetizing past studies, (2) a practical aspect with new results, linking *in situ* and remotely sensed observations and modeling outputs from current studies, (3) a recommendation and prospective for the next decade.

Deliverable 2. **A compendium,** where regional observational systems and numerical simulations are compiled. This compendium will include detailed information about available data in EBUS mainly to answer where to find the observational and numerical data, their characteristics, identify their owners as well as scientific production or published papers.

Deliverable 3. **A high impact factor review paper** (e.g., BAMS)**,** wherein a comparative analysis based on modelling results from both the ocean and atmosphere is presented.

Deliverable 4. **A short recommendation paper, for stakeholders and policy makers** wherein a strategic recommendation will be made on how to more cost effectively design and improve regional observational systems with the overarching goal of improving the performance and reliability of global climate models.

Capacity Building

The **cOCtEAU** WG is planning to hold an international summer school focused on PhD students and young post-docs mainly (but not exclusively) from Africa and South America and other developing countries. The objective will be to provide the young scientists with an integrative view of the land-atmosphere-ocean continuum in their modelling coupled physical/biogeochemical components. The basics of atmospheric physics and chemistry and associated coupler and modelling platforms will be presented. An introduction to regional weather and climate systems off the EBUS will be given, as well as basic concepts in physical oceanography and biogeochemistry and hands-on practicals with the ROMS-WRF-BIOEBUS modelling platform. Statistics applied to climatology and challenges of regional climate downscaling for performing regional climatic projections will be taught. We will try to explore a new, innovative capacity-building concept: the Network of Early Career Scientists (NECS). This will combine traditional capacity-building of individual early career scientists with a new level of institutional networking. The ultimate goal is to build long lasting capacity through training and by interconnecting the next generation of scientists, and to develop enduring institutional interactions that will help address the scientific challenges facing the EBUS.

We will also encourage and facilitate other training and professional development workshops and programmes, such as those funded by the Marie Skłodowska Curie Innovative Training Network. Funding for sustaining our NECS will be sought from a range of sources and stakeholders supporting training and networking measures worldwide. We will collaborate with START, IAI, POGO and APN, so that their fellowship schemes and other mechanisms can be used for capacity development.

It has to be noticed that some scientists involved in the consortium supervise students from southern countries which ocean science community is very small, therefore this WG proposal will also serve as a platform to increase the critical mass of researchers hence reinforcing capacity in oceanic sciences in these developing countries. The Chair of cOCtEAU Working Group being a woman early career scientist originating from a developing country guarantees the very close attention to be given to capacity building.

Additionally, the compendium will be the key material for students and local researchers from the developing countries which have restricted access to peer-review publications due to their limited resources to pay journals subscriptions. In this sense, since the compendium will provide the complete information from observational and numerical data as well as their respective owners and associated scientific production, students and local researchers would be in direct contact with the ocean science community allowing thus to reinforce their capacity building on these topics and at the same time open and expand their international collaborations.

Working Group composition

Full Members

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
1. Curtis Deutsch (USA)	Male	School of Oceanography, University of Washington, USA	Chemical oceanography, biogeochemistry and climate
2. Ming Feng (Australia)	Male	CSIRO Marine and Atmospheric Research	Physical oceanographer specialised in the Leeuwin Current dynamics
3. Sara Fawcett (South Africa)	Female	Department of Oceanography, University of Cape Town, South Africa	Biogechemical Oceanographer, California and Benguela Upwelling Systems
4. Serena Illg (France)	Female	IRD – University of Cape Town, South Africa	Coupled ocean-atmospheric modelling, Upwelling system dynamics
5. Eric Machu (France)	Male	IRD – LPAO-SF, ESP, Université Cheikh Anta Diop, Dakar Sénégal	Oceanographer, structuration of plankton communities from coupled approaches

			(observation & modeling)
6. Baye Cheikh Mbaye (Senegal)	Male	Laboratoire de Physique de l'Atmosphere et de l'Ocean Simeon Fongang (LPAOSF), University Cheikh Anta Diop of Dakar (UCAD)	Physical/biological Oceanography – Senegalese- Mauritanian coastal upwelling within the Canary upwelling system off North-West Africa
7. Ivonne Montes (Peru) **Chair of SCOR WG cOCtEAU**	Female	Instituto Geofísico del Perú (IGP)	Physical Oceanographer, biogeochemical coupled modelling and dynamics of the Peru/Chile System
8. Andreas Oschlies (Germany)	Male	Helmholtz-Zentrum für Ozeanforschung Kiel (GEOMAR)	Physical Oceanography, Marine Biogeochemical Modelling
9. Parv Suntharalingam (UK)	Female	University of East Anglia (UEA)	Oceanographer, biogeochemical modelling
10. Beatriz Yanicelli (Chile)	Female	Centro de Estudios Avanzados en Zonas Aridas (CEAZA)	Oceanographer, Chile Coastal Upwelling System

Associate Members

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
1. Xavier Capet (France)	Male	CNRS-LOCEAN, Paris	Physical Oceanographer - EBUS dynamics, modeller
2. Boris Dewitte (France)	Male	IRD-LEGOS, Toulouse	Physical Oceanographer, Air-sea interactions and climate variability
3. Iris Kriest (Germany)	Female	Helmholtz-Zentrum für Ozeanforschung Kiel(GEOMAR)	Biogeochemical modeller
4. Ryan Rykaczewski (USA)	Male	University of Southern California	Biological Oceanography of EBUS – California System
5. Marcello Vichi (South Africa)	Male	University of Cape Town	Coupled Physical/Biogeochemical Modelling, Earth System Modelling, Process Studies of Biogeochemical Dynamics in the Regional and Global Ocean
6. Siny Ndoye (Senegal)	Male	Cheikh Anta Diop	Physical Oceanographer

		University	

Working Group contributions

All members involved in this SCOR WG will participate in all activities, they have been invited due to their field of expertise and past works, coming from various countries and disciplines; these are:

Dr. Curtis Deutsch is an expert on chemical oceanography, biogeochemistry and climate currently dedicated to contribute to a coherent understanding of the interactions between biogeochemical cycles and the climate system, based on modeling connections between ocean biogeochemistry and climate from human to geological time scales.

Dr. Sarah Fawcett works on understanding the complex relationships between biogeochemical fluxes (particularly nitrogen) and primary productivity in the ocean, with implications for past and future climate, ecosystem structure and function, ocean fertility, and global biogeochemical cycles. Current focus regions include the Southern Ocean and the southern Benguela upwelling system off the west coast of South Africa, which supports high levels of marine biodiversity and human subsistence.

Dr. Ming Feng is specialised in the Leeuwin Current dynamics, impacts of climate variability on the marine environment, and interactions between physical and biological processes in the ocean boundary current and eddies. He has been leading projects in the Western Australian Marine Science Institution on regional projections of climate change impacts and, an Integrated Marine Observing System project to monitor the long term changes in the Leeuwin Current.

Dr. Serena Illg is focussed on the phenology of the EBUS along the coasts of Peru and Chile in the Humboldt Current System and along the coasts of Angola and Namibia in the northern Benguela Upwelling System. She is specialized on the connexion with the linear equatorial dynamics, and on the air-sea interactions at regional and basin scales. Her approaches are based on an inter-comparative analysis of observations, and a combination of simple and complex models.

Dr. Eric Machu is focussed on understanding the role of small scale processes in structuring plankton communities, the energy transfer through the microbial loop and the environmental control of small pelagic fish which dominate these ecosystems. In terms of methodology, both coupled modeling and observations are used to apprehend the underlying processes. He is the Leader of WP3 in the IRD-BMBF AWA project and member of the steering committee of the international joint laboratory ECLAIRS, two projects gathering numerous partners from North-West Africa.

Dr. Baye Cheikh Mbaye is specialised in the Senegalese-Mauritanian coastal upwelling within the Canary upwelling system off North-West Africa. He analyzes how both environmental physical and biological factors affect the survival of fish early life stage (eggs and larvae), and how this ecological understanding could help to make good policies for marine conservation and fisheries management in EBUS, based on both modelling and observations.

Dr. Ivonne Montes is specialized on coupled physical-biogeochemical modelling applied to Eastern boundary current system (Guinea Gulf, Mexico and Peru/Chile) to study the role of the ocean in Climate, investigate the processes maintaining the OMZ off Peru, and the impact of remote and local air-sea interactions in upwelling systems.

Dr. Andreas Oschlies is an expert in Marine Biogeochemical Modelling dedicated to study the physical, biogeochemical, and ecological constraints on the oceanic carbon uptake and its climate sensitivity. He is also interested in mixing processes and their representation in numerical models. He is the coordinator of the collaborative research centre SFB754 "Climate-biogeochemistry interactions in the tropical ocean" at Kiel University and GEOMAR in Germany.

Dr. Parv Suntharalingam is focussed on biogeochemical cycles of climatically important species in the atmosphere and ocean.

Dr. Beatriz Yanicelli has been combining modeling, observational an empirical exerimental approaches to understand the relationship between physical and biogeochemical aspects of EBUS with the ecophysiology and dynamics of marine exploited populations.

Relationship to other international programs and SCOR Working groups

This EBUS theme is one of the Mid-Term Strategy Initiative of the SOLAS international Program[1] and is an integral part of the Integrated topics in the new SOLAS Science Plan 2015-2025[2]. Moreover, CLIVAR and IMBER have a joint Research Focus on Upwelling systems, recently joined by SOLAS. Within Future Earth, the new research initiative on global environmental change and global sustainability, there is a strong willingness to build a Knowledge Action Network on Oceans and the EBUS hold a very favourable position to be selected as one of the focus topics and a proposal to the Belmont Forum on this topic is foreseen for fall 2016. In addition, there is a strong link between this SCOR WG proposal and the new initiative from IOC-UNESCO called GO_2NE (Global Ocean Oxygen NETwork), an interdisciplinary network with particular concerns about the low oxygen concentrations in both the open ocean and coastal areas. This working group is also timely since it fits with concerns of the program TPOS2020 that is aimed at designing the future of the observing system in the Pacific (http://tpos2020.org/). Interactions with the Task Team "Eastern Boundary" of the TPOS2020 program will be encouraged during the

[1]http://www.solas-int.org/about/mid-term-strategy.html

[2]http://www.solas-int.org/files/solas-int/content/downloads/About/Future%20SOLAS/Revised_SOLAS%20Science%20Plan.pdf

*By inversions we mean inversions to obtain information on the properties of materials in the ocean and the atmosphere (gas, particles, dissolved materials, drops etc') as well as at the interface (waves, bubbles). By properties we mean concentration, composition, size and shape, lifetime, optical properties.

course of the SCOR group. This SCOR WG will also have tight links with the SCOR Working Group 144 on Microbial Community Responses to Ocean Deoxygenation which runs between 2014 and 2017. The cOCtEAU WG will interact with WG 144 since one of its objectives is to disseminate standards, data sets and comparative analysis of the oxygen deficient systems in the world ocean to the wider oceanographic and Earth system science communities and the public.

This SCOR WG will also strive to integrate in its synthesis outcomes of relevant regional modeling and observational projects (e.g. CORDEX) through collaborations of its members.

SOLAS is holding a workshop on concurrent remote-sensing inversions of ocean and atmosphere in June 2016 in Frascati, Italy, sponsored by ESA and IGBP funds. It is intended to investigate the benefits and drawbacks of having sensors focused on the ocean and atmosphere (or both) on the same platform/constellation and inverting* ocean atmosphere and clouds together. This will constitute a breakthrough in studying ocean-atmosphere interactions. The cOCtEAU WG will establish contacts with the remote sensing and SOLAS scientists involved in this initiative.

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Title:

Towards the science-based jellyfish observing system

Acronym: **JOS**

Summary/Abstract

The environmental consequences of jellyfish blooms and their impact on some ecosystem services in several marine areas is recognized as a hot topic in several research programs, but much of historical information on jellyfish is anecdotal and obtained using methodology that was not adapted to study this group of marine organisms. Moreover, even currently there is a lack of standardized methodology to assess quantitative field data of both polyp and medusa abundance. The lack of standardized approaches and methodologies was also recognised as important issues during recent International Workshop ‘Coming to grips with the jellyfish phenomenon in the Southern European and other seas’. Further, during discussions it was also stressed that jellyfish need to be monitored on a regular basis and make observations mandatory.

This proposed SCOR Working Group is established with the aim of standardizing and increasing rigour in jellyfish methodology. It will build on interdisciplinary competences of Working Group members what will facilitate the design and development of the proper jellyfish observing system that will encompass modelling and new and emerging technologies. This work will be achieved over a 4 year time period, with a team composed of senior, mid and early career researchers, from both developed and developing countries, what will facilitate capacity building activities. The whole group will focus in particular on field methodology and the establishment of a robust system of observation and forecasting network, towards a reference guide for best practice.

Scientific Background and Rationale

Research into gelatinous organisms has a long tradition and the period at the end of the 19th and beginning of the 20th century is seen as the first golden age of 'gelata' (Haddock 2004), when famous naturalists that studied in particular morphological taxonomy, were fascinated by their beauty and fragility. The environmental consequences of jellyfish blooms and their impact on some ecosystem services in several marine areas during last decades echoed in the popular and news press headlines (Gibbons & Richardson 2013) and refreshed interest in jellyfish research.

Jellyfish blooms have increased in some coastal areas around the world, the outbreaks becoming more severe and frequent over the past few decades (Kogovšek *et al*. 2010). The detrimental socioeconomic impacts on human wellbeing are numerous: some jellyfish are powerful stingers and represent a human health threat (Fenner *et al*. 2010) which also affects tourism (Gershwin *et al*. 2010); they interfere with ship operations and block cooling intakes of coastal industry, power and desalinisation plants (Dong *et al*. 2010); they interfere with fishing causing economic losses to the fishing industry (Quiñones *et al*. 2012); they damage farmed fish (Baxter *et al*. 2011) and act as vectors of fish pathogens (Delannoy *et al*. 2010). Further, they cause a reduction in commercial fish due to predation and competition (Purcell & Sturdevant 2001). In addition to the socioeconomic impact on human wellbeing, it has recently been shown that jellyfish blooms can modify trophic webs and organic matter cycling (Tinta *et al*. 2012). Although there is no clear direct evidence that anthropogenic drivers were responsible for increases, a large amount of correlative evidence suggests such connections and, globally, six of the top ten highly disturbed marine systems (Halpern *et al*. 2008) coincided with locations that have had jellyfish blooms (Purcell 2012).

On the other hand, jellyfish can provide beneficial ecosystem services such as regulating service through carbon sequestration (Lebrato *et al*. 2012), providing food for humans and being a source of novel compounds (Chudakov *et al*. 2010). Jellyfish may serve as prey (Heaslip *et al*. 2012), as a nutrient source (Pitt *et al*. 2009) give shelter (Gasca & Haddock 2004), serve as pelagic biological engineers (Breitburg *et al*. 2010) and host algal symbionts. And finally, jellyfish offer cultural services and attract eco-tourists to places like Jellyfish Lake at Palau (Graham *et al*. 2015).

Among gelatinous marine taxa large pelagic cnidarians and ctenophores seem to be most noxious to humans and a recent review of world oceans listed jellyfish as a mounting threat for future oceans. Medusae that appear "en masse" (bloom) are found primarily within the Scyphozoa which have a bipartite (metagenetic) life cycle (exchange of attached benthic polyp and pelagic medusa) though holoplanktonic species also may form large aggregations (Hamner & Dawson 2009).

Analysis of long-term records (200 years) in the northern Adriatic carried out by Slovenian research group lead by co-proposer of the SCOR WG revealed past periodicity of jellyfish outbreaks and indicated an increasing recurrence pattern in last few decades (Kogovšek *et al*. 2010). Frequent jellyfish blooms were observed in some other productive areas and enclosed seas such as for example East Asian marginal seas (Uye 2008), the Benguela upwelling region (Roux et al. 2013). On the other hand, there has been a hot debate in the literature about global trends in jellyfish populations and interpretations from the available data remained ambiguous (Condon *et al*. 2013). This is partly due to the fact that much of historical information on jellyfish is anecdotal and obtained using methodology that was not adapted to study this group of marine organisms. Moreover, even currently there is a lack of standardized methodology to assess quantitative field data of both polyp and medusa abundance. The lack of standardized approaches and methodologies was also recognised as important issues during recent International Workshop 'Coming to grips with the jellyfish phenomenon in the Southern European and other seas' (Prieto *et al*. 2015). Further, during discussions it was also stressed that jellyfish need to be monitored on a regular basis and make observations mandatory.

This SCOR Working Group is established with the aim of standardizing and increasing rigour in jellyfish methodology. It will build on interdisciplinary competences of WG members what will facilitate the design and development of the proper jellyfish observing system that will encompass modelling and new and emerging technologies.

The proposed working group is composed of senior and some early career researchers what will facilitate capacity building activities. In addition to creation of best practice manual we foresee one open session associated with the International Jellyfish Bloom Symposium (2019) that is attended by senior and younger researchers from developed and developing countries.

Terms of Reference

1) To review and evaluate past and present methodology of jellyfish field surveys.

2) To review 'instrumental' approaches for jellyfish collection and abundance determination.

3) To identify new/emerging technologies that may improve jellyfish monitoring.

4) To identify formulae, parameters and approaches to model jellyfish.

5) To develop protocols/methodology for global comparisons.

6) To develop priorities and recommendations for future monitoring efforts.

Working plan

We outlined 6 Terms of Reference for the JOS SCOR Working Group (WG). These Terms of Reference will each be fulfilled as actions items between and/or during WG meetings. In order to minimize travel costs, we will run each meeting alongside international conferences (January 2017, June 2019) and the training course (September 2020) that are outlined in the Timetable below.

Year 1

Kick-Off Meeting for the JOS Working Group

Even that the activities for the first year of the Working Group (WG) are mainly on review processes (see Timetable and Deliverables), we consider very important to have a Kick-Off Meeting in order to stir up the WG. We have explore three possibilities to run such a Meeting and they are not ordered by preference:

1) The ASLO Aquatic Science Meeting to be held in Honolulu (Hawaii, USA) on 27 February to 3 March 2017. The session proposals are due 2 May 2016, but as the resolution of the funded SCOR WG will not be known before that deadline, in case of funded and only if a high percentage of JOS Members will plan to attend it, then we will decide that the Kick-Off Meeting to be held followed of ASLO ASM 2017. http://aslo.org/meetings/sessions/

2) The Third Xiamem Symposium on Marine Sciences (XMAS-III) to be held in Xiamem (China) on 9-11 January 2017. This Symposium is very early on the First year but as Professor Sun is Chief Scientist of a Key action of NSFC (XMAS-III is half organized by NSFC) and the program is still open, then is easy to organize a along-side session of our WG. http://mel.xmu.edu.cn/conference/3xmas/

3) In case any of the two previous options can be performed (either for time schedule or because the percentage of WG attendees to those symposiums would be two low), then the Kick-Off Meeting will be held through WebEx (or similar platforms) during January 2017.

Activities:

The proposed WG will focus on Terms of Reference #1 and #2 to develop the point of departure for JOS. At the beginning, the two Co-Chairs will initiate this state-of-the-art so a draft can be circulated to stimulate discussion at our inaugural meeting. During the rest of the year, the WG will work on Deliverable 1 (see list of the deliverables) in order to summarize the state-of-the-art methodologies and instrumental approaches of jellyfish field surveys.

Year 2

Activities:

The proposed WG will focus on the Term of Reference #3. The WG will work on the achievement of Deliverable 2 “Synthesis new/emerging technologies”. Due to the fast developing ocean technology together with the fact that jellyfish are delicate organism, hard to sample and to preserve (characteristics that have may its field of study difficult until just recently), this issue is on main importance for the JOS WG.

Based in the experience of Co-Chair Dr. Malej and Dr. Schiariti on new and emerging technologies, together with the experience in this matter in 6 of the Associate Members (Dr. Tintoré, Houghton, Uye, Kampel, Purcell and Hosia), the means to achieve successfully this action of the proposal are ensured.

Year 3

Activities:

During this third year, the group will work on the Term of Reference #4, specifically focused in the formulae, parameters and approaches to model jellyfish. This issue demands not only the expertise of the modelers of the Working Group (Professor Oguz as Full Member and Diego Macías as Associate Member), but also the knowledge of the whole team, including the experts on field research, laboratory experiments, population dynamics, environmental drivers, trophic connections and impact on socioeconomics (i.e. fisheries and tourism). All this work will be mirrored in the Deliverable 4.

The second JOS Working Group Meeting will be held followed by JBS 2019 (see Timetable and Capacity Building), but along-side the JBS, we will perform the Deliverable 3 “Presentation of JOS WG actions at JBS 2019” in order to ensure that the new methods and technics for jellyfish research will reach the large community of jellyfish researchers as well as new generations of scientist.

Year 4 and looking beyond the lifetime of the JOS WG

Activities:

The final two Terms of Reference (#5 and #6) will be fulfilled in year 4, and together with prior Terms of Reference #3 and #4, will provide a range of protocols/methodology for global comparisons, including priorities and recommendations for future monitoring efforts.

Looking beyond the lifetime of the JOS Working Group, a training course (Deliverable 5) will be performed in one of the developing countries that form part of this proposal (see Capacity Building section) in order for the WG to perform teaching and training activities. This training course will be performed along-side the third and last WG Meeting. The fact that we plan to do it in October, we can work in the wrap up of the JOS WG to achieve the last Deliverable 6.

Even that Dr. Issidri and Dr. Schiariti are task to lead the Capacity Building activities of the group, in case that the Training Course could not be performed finally neither in Morocco nor Argentina, then these two Full Members will act as part of the Organization Committee and the Training Course could be performed in Sao Paulo (Brazil) as two of the Associate Members, Dr. Morandini and Dr. Kampel, are from that site.

Finally, there is the possibility that, instead of performing the Deliverables #1, #2, #4 and #6 as separate articles, we will performed a join effort to concentrate the outcomes of the JOS WG in just one issue with several articles steaming from the work performed in a special open-access issue in a refereed scientific journal of very high impact. This potential possibility will be discussed with the Full Members in order to check for potential funds among us during year 1. In case we do have the funds, then we will contact the target journals and we will inform the SCOR Committee regarding this change in the timetable of the planning work before the end of year1.

Timeline

Calendar Year	Key Dates	WG activity
2016	April: Submission of proposal Nov-Dec: Decision by SCOR on support	Preparation of JOS WG proposal
2017	Jan-Feb: kick-off meeting Oct: publish state-of-the-art of the topic	We will work on Deliverable 1 “Summarize the state-of-the-art methodologies and instrumental approaches of jellyfish field surveys”
2018	Oct: publish synthesis new technologies	The WG would focus on Deliverable 2 “Synthesis new/emerging technologies”
2019	May-June: JBS 2019 (the place to be held will be decided during June 2016 in the JBS 2016). Working Group meeting followed by JBS2019 Oct: publish synthesis modeling	Performed the Deliverable 3 “Presentation of JOS WG actions at JBS 2019” as a along-side session During this year the WG would release Deliverable 4 “Synthesis of formulae, parameters and approaches”
2020	Sept-Oct: Working Group meeting in a developing country followed by the training course. Nov-Dec: crystalize the wrapping up of the Working Group achievements.	Training course in a developing country (Deliverable 5) The WG presents its conclusions through Deliverable 6 “Publication of a reference handbook of protocols/ methodology for global comparisons and for future monitoring”, including the means to future update of it

Deliverables

Deliverable D1: associate to the Terms of Reference # 1 and 2. Communicate this state-of-the-art as a Review paper to a refereed scientific journal as an open-access article (end of year1).

Deliverable D2: associate to the Term of Reference # 3. Communicate this state-of-the-art as a Synthesis paper to a refereed scientific journal as an open-access article (end of year2).

Deliverable D3: associate to the Terms of Reference # 1, 2, 3 and 4. Coordinate an along-side “session” at the international Jellyfish Bloom Symposium (JBS) 2019 to attract and disseminate our WG actions to other young researchers and to the broader jellyfish community (middle of the year3).

Deliverable D4: associate to the Term of Reference # 4. Communicate this state-of-the-art as a Synthesis paper to a refereed scientific journal as an open-access article (end of year3).

Deliverable D5: Training Course in a developing country, organized by either Dr. Issidri or Dr. Schiariti, where the JOS WG plans teaching and training activities in conjunction with the working group meeting.

Deliverable D6: associate to the Terms of Reference # 5 and # 6. The outcome and conclusions of these two actions will be published either as a handbook of reference (with its ISBN) that can be free-downloaded or as Synthesis paper to a refereed scientific journal as an open-access article (end of year4). In order to those protocols can be readily updated and accessed on line, the WG will provide the means (i.e. web site) to achieve it.

Capacity Building (How will this WG build long-lasting capacity for practicing and understanding this area of marine science globally)

The primary need from the jellyfish community in order to standardize protocols and advance in the study of field abundance estimates is to create a manual that can be applied globally, easily and with low cost. Given the need for long-term (i.e., well beyond the lifetime of a 4 year WG) and sustained international research into abundance estimates of jellyfish on the field, we have in part detailed some of our longer term aspirations in our working plan under the section “Year 4 and looking beyond the lifetime of the JOS WG”.

Our Full Member team already includes young scientists from developing countries (Dr. Issidri from Morocco), from countries with economies in transition (Dr. Schiariti from Argentina) and also from well develop countries (Lucas Brotz from Canada). This new generation of scientist, together with the senior scientist of the team (Professors Malej, Oguz, Song and Shiganova) and the mid carrier scientist (Drs. Prieto, Pitt and Gibbons), makes the JOS a solid based WG that will ensure the knowledge to be maintain further on.

Dr. Issidri and Dr. Schiariti are task to lead the capacity building activities of the group. The combination of one Training Course for early career scientists to be held almost at the end of the year 4 in either Morocco, Argentina or Brazil (see more details in the working plan), being developing countries or with economies in transition, with the fact that the next Jellyfish Bloom Symposium (JBS) will be in 2019 (around the middle of the year 3 of this SCOR WG) can ensure that the new methods and technics for jellyfish research will reach the large community of jellyfish researchers as well as new generations of scientist. In this line, the JOS WG we plan an along-session during the JBS 2019 and invite early career scientists to join the session. The JOS WG will meet meeting as a second time followed of JBS 2019. In the training workshop held in the developing country, the JOS WG plans teaching and training activities in conjunction with the third working group meeting.

Furthermore, the JOS WG will bring Associate Members from developing countries (Drs.

Morandini and Kampel) to WG meetings, together with the possible maximum of the rest of the Associate Members team.

Therefore, we expect that the outcomes of this proposal WG will ensure a new generation of scientists, from a wide range of countries, with comprehensive skillsets to further evolve the field of jellyfish research, taking into account the new and fast developing ocean technologies. For that, the JOS WG will published a handbook reference to standardized methodology for field jellyfish research, but providing the means (web site or a jellyfish network) in order to those protocols can be readily updated and accessed on line by the emerging international community of both established and emerging early career researchers.

Working Group composition

Full Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Laura Prieto (Co-chair)	Female	CSIC, Cadiz, Spain	Population dynamics of jellyfish and multiple drivers
2 Alenka Malej (Co-chair)	Female	NIB, Piran, Slovenia	Field survey and jellyfish abundance new technologies
3 Agustin Schiariti	Male	INIDEP, Mar del Plata, Argentina	Jellyfish ecology and implications for fishery management
4 Hounaida Farah Idrissi	Female	INRH, Casablanca, Morocco	Coastal field surveys and zooplankton
5 Kylie Pitt	Female	Griffith University, Southport, Australia	Trophic ecology of jellyfish, field surveys and meta-analysis
6 Lucas Brotz	Male	University of British Columbia, Canada	Jellyfish populations trends and jellyfish fisheries
7 Mark Gibbons	Male	University of the Western Cape, South Africa	Jellyfish dynamics and climate change
8 Tamara Shiganova	Female	RAS, Moscow, Russia	Field survey and laboratory experiments of gelatinous plankton
9 Temel Oguz	Male	Middle East Technical University, Turkey	Ecosystem modeler to study the impact of gelatinous plankton on food webs
10 Sun Song	Male	Institute of Oceanology Chinese Academy of Sciences, China	Jellyfish blooms, mechanism, processes and ecological consequences

Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Aino Hosia	Female	University of Bergen, Norway	Jellyfish field survey sampling and optical platforms
2 Andre Morandini	Male	Universidade de São Paulo, Brasil	Biodiversity of jellyfish
3 Areti Kontogianni	Female	University of Aegean, Greece	Socio-economics impact of Jellyfish.
4 Diego Macías	Male	JRC, Ispra, Italy	Ecosystem and IBM modeler of jellyfish
5 Ferdinando Boero	Male	Università del Salento / CoNISMa / CNR-ISMAR, Italy	Zoology, ecology and citizen science of jellyfish
6 Jennifer Purcell	Female	Western Washington University, U.S.A.	Field research on jellyfish for 40 years, including new optical approaches
7 Joaquín Tintoré	Male	SOCIB, Palma de Mallorca, Spain	Physical oceanographer. Operational oceanography and new ocean technologies
8 Jonathan Houghton	Male	Queen's University Belfast, U.K.	Ship-borne, aerial surveys and lab-based techniques to study jellyfish
9 Milton Kampel	Male	Instituto Nacional de Pesquisas Espaciais – INPE, Brasil	Remote sensing (color oceanic indicator of swarms)
10 Shin-ichi Uye	Male	Hiroshima University, Japan	Jellyfish biology/ecology and technological development in early forecast of bloom

Working Group contributions

Laura Prieto (Spain, Co-chair). Dr. Prieto research focuses on the influence of multiple drivers (climate, atmospheric, oceanographic) on jellyfish population dynamics. Her last publication (top 5% by Altmetric, 1 week cover of JRC web of the European Comission), untangled the reasons why a swarm of dangerous jellyfish entered on the Mediterranean basin.

Alenka Malej (Slovenia, Co-chair). Dr. Malej has been involved in field and laboratory research of jellyfish for more than 30 years. Her research is focused on trophic interactions, population dynamics, temporal and spatial distribution including connectivity of populations (genomic approach) and, more recently, their socioeconomic impacts.

Agustin Schiariti (Argentina). Dr. Schiariti is particularly interested in the potential effects of these organisms on the recruitment of fishing resources and their implications for fishery management, including the development of a jellyfish fishery in Argentina.

Hounaida Farah Idrissi (Morocco). Dr. Idrissi works on gelatinous macrozooplankton in the Moroccan ecosystem: species identification, spatial occurrences of the observed species, trophic interactions and their environment. Now, her team is exploring how to integrate ROVs technology in the jellyfish observation in coastal waters.

Kylie Pitt (Australia). Dr. Pitt expertise focuses in population dynamics of jellyfish, their response to climate change, their trophic ecology and roles in nutrient cycling. Her research spans local to global scales and utilizes experiments (field and laboratory) and meta-analyses of existing global data.

Lucas Brotz (Canada). Brotz has expertise in population trends for jellyfish around the globe and in the factors that influence jellyfish populations, as well as the monitoring of jellyfish from a wide range of spatial/temporal scales. His most recent work is focus on jellyfish fisheries and on developing a protocol for monitoring jellyfish bycatch.

Mark Gibbons (South Africa). Dr. Gibbons has worked to collate fisheries-dependent and fisheries-independent data on jellyfish populations, and to describe their dynamics over a variety of temporal/spatial scales. He has also stimulated research into the use of hydroacoustic tools to map jellyfish biomass and distribution.

Tamara Shiganova (Russia). Dr. Shiganova has been working from more than three decades with gelatinous plankton focusing on invasive ctenophores in the Mediterranean, Caspian and Baltic Seas and their impact on ecosystem. She is involved in field and laboratory research.

Temel Oguz (Turkey). Prof. Oguz is a leading ecosystem modelers to study the impact of gelatinous predators on functioning of food web structures. His fundamental contribution is modeling the response of top-down control exerted by gelatinous carnivores on the Black Sea pelagic food web and a coupled plankton–anchovy population dynamics model assessing relative roles on the nonlinear controls of small pelagic fishes and gelatinous species.

Sun Song (China). Prof. Sun research is focused in zooplankton and ecosystem dynamics. He is the Chief Scientist of the National Basic Research Program of China: “Jellyfish bloom in the Chinese waters, mechanism, key processes and ecological consequences”, of the Key NSF of China: “Zooplankton functional group variation and ecosystem dynamics in the Yellow Sea and East China Sea” and of the Pioneer research project of CAS: “Western Pacific Ocean System: Structure, Dynamics and Variation”.

Relationship to other international programs and SCOR Working groups

The proposed Working Group is a good mechanism to advance in this topic (Towards the science-based jellyfish observing system) at global scale as it will provide a network of scientist from all the continents that would be unlikely to be supported through different national sources.

In this sense, this proposal aims to consolidate and improve the methodology for jellyfish research and to increase our capacities to forecast nuisance jellyfish phenomena. WG will focus in particular on field methodology and the establishment of a robust system of observation and forecasting network, towards a reference guide for best practice. This proposal stemmed from a last year IMBER endorsed initiative, lead by Dr. Prieto (Co-Chair), titled “Coming to grips with the jellyfish phenomenon in the Southern European and other Seas: research to the rescue of coastal managers”, an International Jellyfish Workshop funded by IOC-UNESCO, UE and CEIMAR (http://www.perseus-net.eu/site/content.php?locale=1&locale_j=en&artid=2539).

The proposed team is formed with active members in different international programs:

Dr. Malej (Co-Chair) is a Board Member of the Bureau Central de la Commission International pour l'Exploration Scientifique de la Mer Mediterranée (CIESM) (http://ciesm.org/people/board/index.htm) and in the past she served as chairperson of the National Committee for the Intergovernmental Oceanographic Commission (IOC) and national MED POL co-ordinator of UNEP MAP (United Nations Environmental Programme, Mediterranean Action Plan).

Prof. Sun, is Executive Member of Partneship for Observation of the Global Oceans (POGO) (http://www.ocean-partners.org/) and Member of The Global Ocean Observing System (GOOS) Steering Committee (IOC-UNESCO) (http://www.ioc-goos.org/). At national level, he is the Chairman of China Oceanology and Limnology Society; vice chairman of the China Marine Fisheries Society; and Vice Chairman of the Chinese Oceanographic Society.

Dr. Shiganova is actually one of the Committee Chairs of CIESM for “Living Resources and Marine Ecosystems” (http://ciesm.org/people/chairs/index.htm).

Dr. Uye has been a co-chair of PICES (North Pacific Marine Science Organization) WG on “Jellyfish blooms around North Pacific Rim: Causes and consequence” that recently submitted its final report. In that group were also Dr. Jennifer E. Purcell and Lucas Brotz.

Dr. Tintoré is Vice-Chairman of the Marine Board of the European Science Foundation (http://www.marineboard.eu/) and he is Director of the Spanish Large Scale Marine Infrastructure, SOCIB (Balearic Islands Coastal Ocean Observing and Forecasting System) (http://www.socib.eu/index.php?seccion=home).

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Appendix

For each Full Member, indicate 5 key publications related to the proposal.

Laura Prieto

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Kylie Pitt

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SCOR Working Group Proposal

Title

Eastern Boundary Upwelling Ecosystems (EBUE): inter-comparisons, variability and forecasting responses to climate and global change

Acronym

EBUE

Abstract

A SCOR working group (WG) on Eastern Boundary Upwelling Ecosystems (EBUE) is proposed. The focus of this WG would be on: 1) Assessing the trends and drivers of oceanographic, ecological and socio-economic properties in EBUE; 2) Assessing how well the current generation of coupled physical-biogeoecological models can reproduce the mean and current trends; 3) Developing a common observational and modeling framework for upwelling systems that will yield improved predictions of climate and global change; 4) Developing a list of realistic governance actions for EBUE based on current trends and model forecasts 5) Promoting integrated international EBUE scientific cooperation through organizations such as IMBER, CLIVAR, SOLAS, GlobalHAB and PICES; 6) Developing capacity so that an integrated program of comparable observations and models can be promoted across EBUE. We propose a strong team with broad scientific expertise in observations, modeling and socio-economics, and the four major coastal eastern boundary upwelling regions, i.e. California, Humboldt (Peru and Chile), Canary and Benguela. The team will review physical, biogeochemical, biological, fish and fisheries processes and trends, and their socio-economical impacts. Forecasts from global and higher resolution regional models will be analyzed. Potential effects on fisheries and other ecosystem services will be explored and a list of potential management strategies developed. The WG will develop a common observational and modeling framework for EBUE expected to yield improved predictions of climate and global change. It will promote international EBUE scientific cooperation through organizations such as IMBER, CLIVAR, SOLAS, GlobalHAB and PICES, and an integrated international program to implement the observational and modeling framework developed by the WG. The results will be published in primary scientific and socio-economic journals, and technical reports.

Scientific Background and Rationale

Eastern boundary upwelling ecosystems (EBUE) have fascinated oceanographers and fisheries scientists for decades. The strong coupling between atmospheric forcing, ocean circulation, biogeochemical cycling, and productive fisheries encouraged multidisciplinary scientific studies that have now become common. In EBUE temporal and spatial scales are intimately linked. The upwelling process and associated current system can segregate the sources (nutrients, phytoplankton, zooplankton) from the sinks (phytoplankton, zooplankton, fish) and make the biological pump a fully four-dimensional process. As a conglomerate, the EBUE produce almost 20% of the global marine fish harvest while occupying only a small fraction of the area. In the 21st Century human pressure on these productive ecosystems and their services is increasing, requiring new and evolving scientific approaches to the collection of information and its use in management. The EBUE are increasingly vulnerable to the multiple effects brought on by ocean acidification, deoxygenation, harvest of marine resources and coastal development. The complex four-dimensional nature of EBUE challenges the development of the system-level understanding that is needed to predict the effects of these stressors on marine ecosystems and humans at multiple scales. There are currently several evolving programs on EBUE, mostly focused on the impacts of a varying and changing climate on these productive ecosystems. CLIVAR (Climate and Ocean: Variability, Predictability and Change), one of the four core projects of the World Climate Research Programme, hopes to improve how EBUE are simulated in global climate models; these systems are presently poorly represented. The Surface Ocean – Lower Atmosphere Study (SOLAS) has air-sea fluxes at eastern boundary upwelling and oxygen minimum zone systems as a mid-term strategy. There is an evolving plan presented to the United Nations Framework on the Convention for Climate Change for EBUE as sentinels of climate change and potential to be pilot programs for adaptation policies. IMBER recently convened a workshop focused on identifying key societal needs in EBUE, scientific gaps, and means to fill them. Here we propose a SCOR Working group on EBUE with the following deliverables: 1) A common observational and modeling framework for upwelling systems that will yield improved predictions of climate and global change; 2) A list of key indicators of change that can be used in such a framework; 3) An international implementation plan that integrates programs such as CLIVAR, IMBER, SOLAS, and GlobalHAB.

It is particularly timely to focus on eastern boundary upwelling ecosystems and their variability. The EBUE can serve as sentinels of marine ecosystem health and response to natural/anthropogenic perturbations. Ocean upwelling regions contain the world's most productive fisheries (Pauly and Christensen, 1995), mainly associated with eastern boundary currents (EBCs; e.g. Humboldt , Benguela, Canary current systems) but also in western boundary currents (WBCs; e.g. Kuroshio, Gulf Stream, Agulhas, East Australian), along the equator, off Antarctica, and elsewhere. Upwelling results from wind forcing against a coast in the case of EBCs, owing to change in sign of the Coriolis force at the equator, or through dynamic uplift as in WBCs. The rate and duration of upwelling influence the amount of biological production, hypoxia and pH levels. Upwelling rate determines the phytoplankton cell size (Van der Lingen et al., 2011). Small phytoplankton dominate when the upwelling rate is extremely strong or weak, resulting in extra trophic levels between the algae and fish, which reduces fish production. In contrast, large-sized phytoplankton dominate under moderate upwelling and production is then transferred more directly to fish via large zooplankton grazers. Further, upwelling rate may determine the plankton and fish community structure, given that different fish species are better suited to preying upon plankton of different sizes (van der Lingen et al., 2006).

A major current issue is anthropogenic climate variability and global change, and the individual EBUE are reacting differently. Projected increased winds under climate change in EBCs could result in increased upwelling (Bakun, 1990), but global warming should strengthen thermal stratification and cause a deepening of the thermocline and reduce upwelling (Bopp et al., 2005). Recent observational evidence in different regions have shown increases (Bakun, 1990; McGregor et al., 2007; Narayanan et al., 2010; Blamey et al. 2012), decreases (Gomez-Gesteira et al., 2008) or no change (Demarcq, 2009) in upwelling intensity. The upwelling response depends on the interactions between land, atmospheric structures and the ocean. Further work on the upwelling trends under climate change is needed to determine the balance between cooling due to increased upwelling (where it exists) and warming due to climate change as how the rate, duration and seasonality of upwelling, and hence fisheries, will be affected.

Upwelling systems typically are poorly represented in dynamic models owing to the small spatial scales of the upwelling relative to the horizontal resolution of the global models (Stock et al., 2011). Particularly. EBCs are often associated with warm temperature biases that strongly limit the prediction of future evolution. Increased model resolution improves simulations of the regional climate and affects the large-scale climate system through feedbacks (Large and Danabasoglu, 2006; Curchitser et al., 2011). Basin-scale physics are also a critical determinant of regional upwelling variability (Rykaczewski and Dunne, 2010). Using the most recent global and regional models will help to meet some of the challenges in developing upwelling scenarios under future climate change, including biogeochemical impacts (nutrients, primary production, deoxygenation, acidification), fisheries effects and subsequent influences on the dependent fishing industries and fishing communities (Blanchard et al. 2012, Barange et al., 2014) – highly relevant in today's climate of an Ecosystem Approach to Fisheries and today's need to maximize food production and security.

Terms of Reference

This WG will:

1. Summarize and review current trends and drivers of oceanographic, ecological and socio-economic properties in each EBUE.
2. Compare trends and drivers between EBUE and summarize similarities and differences.
3. Develop a list of key indicators in EBUE that can be readily used to assess change across EBUE.
4. Prepare protocols for measuring key properties and indicators in EBUE.
5. Summarize and review model results for EBUEs and assess the strengths and weaknesses.
6. Develop a common observational and modeling framework for upwelling systems that will yield improved predictions of climate and global change.
7. Describe the usefulness of current observations and model forecasts for governance activities in EBUE.
8. Develop capacity in developing countries so that collection of comparable observations development of comparable models across EBUE can be implemented .
9. Promote international EBUE scientific cooperation through organizations such as IMBER, CLIVAR, SOLAS, GlobahHAB, and PICES.
10. Promote an integrated international program that will implement the observational and modeling framework developed by WG.

<u>Year 1 (2017)</u>

The first year will be focused on organizing the Working Group and assembling the information needed to achieve deliverables 1 and 2 (see below). An initial meeting of the Working Group in a location convenient to the WG is proposed, perhaps at MBARI or Rutgers. These institutions can provide local meeting venues and administrative support at no cost to SCOR. At this meeting the capacity building activities will be planned for Year 2 in addition to beginning the collection of material for deliverables 1 and 2. Clear plans and responsibilities will also be developed, identifying leads for each deliverable. Mechanisms for WG communication and exchange will be established. At this meeting we would also identify promising graduate students from developing countries who might take advantage of the WG activities and potentially lead certain aspects of the research.

<u>Year 2 (2018)</u>

Two one-week meetings in Peru and Chile are proposed for Year 2. The first week the WG will meet in Peru for two days followed by a 3-day short course in support of a recently established Master's Program at the Universidad Cayetano Heredia (Gutierrez is faculty). The following week the same schedule will be followed in Chile at the Universidad de Concepcion (Escribano is Faculty). The topics of the courses will be developed in close consultation with local scientists, but touch on EBUE dynamics, response to climate variability and change, and impacts on fisheries and ecosystem services. The local organizers will provide meeting venues and administrative support at no cost to SCOR. The courses will be open to students from any university, including other South American countries. The WG will request funding from SCOR and other sources to help students and early-career scientists participate. During the WG meetings the progress on deliverables will be reviewed, with particular emphasis on the Humboldt EBUE. Local experts will be invited to the WG meetings. See note at end of Year 3 plans regarding budget.

Year 3 (2019)

A similar sequence will be followed early in Year 3 but focusing on Northwest Africa and Benguela. Again, two weeks, one week in NW Africa (Aristegui lead), followed by a second in Benguela (Moloney, lead). Locations to be determined. Local organizers will provide meeting venues and administrative support at no cost to SCOR. The courses will be open to students from any university, including other African countries. The WG will request funding from SCOR and other sources to help students and early-career scientists participate. During the WG meetings the progress on deliverables will be reviewed, with particular emphasis on the North and South Africa EBUE. Local experts will be invited to the WG meetings. We expect completed first drafts and submissions of deliverables 1-3 by the end of Year 3. Having two-week meeting in two geographic locations in two years will be difficult to achieve within the budget allocated to SCOR WGs and we will seek other sources of funds to implement the proposed meeting schedule. Should funds not be found we would scale back to single meetings in South America (2018) and Africa (2019).

Year 4 (2020)

We presently do not anticipate the need for a face-to-face meeting in Year 4, although this could change depending on progress, new developments and available funds. We anticipate completion of the full set of deliverables by the end of Year 4.

Deliverables

1. Prepare a scientific review of current trends and drivers of oceanographic, ecological and socio-economic properties in EBUE. The review will compare trends and drivers between EBUE and summarize similarities and differences. Suggested target journal is *Nature Climate Change*.
2. Prepare a scientific review of numerical model results for EBUEs and assess the strengths and weaknesses of different models. Compare model results with trends and drivers developed above. Suggested target journal is *Nature Climate Change*.
3. Based on 1 and 2 develop a common observational and modeling framework for upwelling systems that will yield improved predictions of climate and global change. This framework will utilize key indicators identified by the WG for EBUE that can be readily used to assess change across EBUE. In support of the framework the WG will prepare protocols for observations of key properties and indicators in EBUE and the required model parameters and resolution. Journal TBD.
4. The WG will utilize current observations and model forecasts to develop a list of proposed governance activities for each EBUE. Journal TBD
5. A white paper describing an integrated international program that utilizes the observational and modeling framework developed by WG with proposed implementation by EBUE nations and international organizations such as IMBER, CLIVAR, SOLAS, GlobalHAB, and PICES.

Capacity Building

An online course on "EBUE dynamics, response to climate variability and change, observations, modeling and impacts on fisheries and ecosystem services " will be assembled based on the four short courses during Years 2 and 3. This course will be made freely available to graduate and postgraduate students and offered in an open system by 2019. It will be offered first in English and then other languages as well. We will also support involvement of graduate students in WG activities and meetings, including presentations and publication of results. A set of best practices for key observations and indicators will be developed, mostly by combining published protocols (i.e. ocean acidification). A similar exercise will be carried out with models.

The project will also promote the integration of an international network of scientists (observationalists and modelers) working in upwelling systems and use this network to identify common problems and experiences. By involving scientists and students from developing countries throughout the WG process we expect to increase the number and quality of scientists from these countries working in EBUE leaving a long lasting imprint.

Working Group composition

Full Members – We have sought to balance the team by discipline, participants from developed and developing countries, and gender. As a result of the overall balancing we are weaker in gender balance than we would have preferred.

	Name	Gender	Place of work	Expertise/ Area
1	Francisco Chavez	Male	USA (co-chair)	Biological Oceanography/ California, Peru
2	Javier Aristegui	Male	Spain	Biogeochemistry/ Northwest Africa
3	Colleen Moloney	Female	South Africa	Biogeochemistry, modeling/Benguela
4	Ruben Escribano	Male	Chile (co-chair)	Biological Oceanography/ Chile/ IMBER
5	Dimitri Gutierrez	Male	Peru	Biogeochemistry, Oceanography/ Peru
6	Enrique Curchitser	Male	USA	Physical Oceanography Modeling /CLIVAR
7	Nicolas Gruber	Male	Switzerland	Oceanography, Biogeochemistry, Modeling
8	Manuel Barange	Male	UK	Fisheries/Socio-economist, ecology
9	Salvador Lluch-Cota	Male	Mexico	Fishery/Socio-economist ecology
10	Sophie Bertrand	Female	France	Ecology, Conservation

Associate Members

	Name	Gender	Place of work	Expertise/ Area
1	Xosé Alvarez Salgado	Male	Spain	Biologist/Canary EBUE
2	Ryan Rykaczewski	Male	USA	Biological Oceanography/EBUE
3	Des Barton	Male	Spain	Physical oceanographer/ Modeling EBUE
4	Paquita Zuidema	Female	USA	Physical Oceanography/ Modeling EBUE
5	Veronique Garcon	Female	France	Biological Oceanography/EBUE
6	Shoshiro Minobe	Male	Japan	Oceanography/climatology Modeling EBUE

7	Lynne Shannon	Female	South Africa	Fishery/Socio-economist ecosystem EBUE
8	Holger Auel	Male	Germany	Biological Oceanography/EBUE
9	Carl van der Lingen	Male	South Africa	Fishery Oceanography/ Benguela
10	Marisol García Reyes	Female	Mexico	Biogeochemistry/EBUE

Working Group contributions

Francisco Chavez, co-chair, has published extensively on climate variability and EBUE, worked for many decades on the California and Humboldt EBUE, and has broad interests in oceanography, biogeochemistry, ecology, modeling, and new technology. He has led several synthesis efforts, edited multiple special issues and is active in national and international programs.

Ruben Escribano, co-chair, is a biological oceanographer who specializes in zooplankton, was active in the GLOBEC program and is presently on the IMBER scientific steering committee. He has worked extensively on the Humboldt EBUE and will lead the capacity building effort.

Enrique Curchitser is a physical oceanographer with interests in the dynamics of eastern boundary currents and shelf circulation and coupled bio-physical and numeric modeling. He is leading the CLIVAR Eastern Boundary Upwelling Research Focus that is trying to better understand the very large biases that climate models have in EBUE.

Sophie Bertrand is a marine ecologist who is interested in the spatial relationships between fish, seabirds, marine mammals and humans in productive EBUE so that better management can be developed to permit animals and humans to sustainably cohabitate. She is a member of MARBEC (MARine Biodiversity, Exploitation and Conservation).

Nicolas Gruber leads the Environmental Physics group at ETH in Zurich that studies interaction between biogeochemical cycles and climate from global to regional levels. One research focus is on the eastern boundary upwelling systems of the Atlantic and the Pacific Ocean where they use the Regional Oceanic Modeling System (ROMS) coupled to biogeochemical-ecosystem models (NPZD and BEC) to investigate how physical, chemical and ecological processes respond to natural and anthropogenic change.

Manuel Barange has expertise in physical/biological interactions, climate and anthropogenic impacts on marine ecosystems, fish ecology, behavior and trophodynamics, and fisheries assessment and management. Recently he has focused on the impacts of climate change and economic globalization on marine-based commodities, and on the interaction between natural and social sciences in fisheries, ecosystems and climate change in the developed and developing world.

Collen Moloney has broad research interests in the variability and dynamics of marine food webs and ecosystems under global change and locally on the marine ecosystems of the west and south coasts of southern Africa, part of the Benguela EBUE. She utilizes field and modelling studies to understand “end-to-end" ecosystem responses to global change, determined by complex interactions and feedbacks among physical, chemical and biological processes spanning many time and space scales.

Salvador Lluch-Cota has interests in climate variability and change and its effects on living marine resources; he was one of the six lead authors of the IPCC chapter on Ocean Systems. He has worked extensively in the California Current System particularly off Baja California, Mexico and has led synthesis efforts to uncover and better understand the variability of small pelagic fish in Atlantic and Pacific EBUE.

Javier Aristegui is based in the Canary Islands and much of his work is focused on the Northwest Africa EBUE, studying the influence of mesoscale and sub-mesoscale processes on planktonic community structure and metabolism, and the role that these features play in the export of carbon from coastal waters to the open-ocean. He is a past vice-chair of the IMBER Scientific Steering Committee, led an international symposium on EBUE, is an author of IPCC reports and contributed to the Joint SOLAS-IMBER Carbon Cycle Research Plan.

Dimitri Gutierrez is head of the Oceanography and Climate Change division at the Instituto del Mar del Peru, has broad research interests in EBUE, climate variability, oceanography, benthic communities and paleo-oceanography and will co-lead capacity building activities with Dr. Escribano. He has recently led a successful proposal to the World Bank to implement a climate change adaptation program for Peruvian coastal communities where small-scale fisheries are critical elements of society.

Relationship to other international programs and SCOR Working groups

This program has clear linkages to CLIVAR, IMBER, SOLAS, GlobalHAB and UNFCC. CLIVAR (Climate and Ocean: Variability, Predictability and Change), one of the four core projects of the World Climate Research Programme, hopes to improve how EBUE are simulated in global climate models; these systems are presently poorly represented. SOLAS (Surface Ocean - Lower Atmosphere Study) has air-sea fluxes at eastern boundary upwelling and oxygen minimum zone systems as a mid-term strategy. There is an evolving plan presented to the United Nations Framework on the Convention for Climate Change for EBUE as sentinels of climate change and potential to be pilot programs for adaptation policies. IMBER (Integrated Marine Biogeochemistry and Ecosystem Research) recently convened a workshop focused on identifying key societal needs in EBUE, scientific gaps, and means to fill them. There is also relation to IOC sponsored projects such as GOAN (Global Ocean Acidification Network), GO_2NE (Global Oxygen Observation Network), and GlobalHAB (Harmful Algal Blooms). The Humboldt EBUE relates to the Tropical Pacific Observing System 2020 initiative.

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Appendix - Key references for each full member (up to 5 papers)

Francisco Chavez

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Proposal for a SCOR-WCRP Sponsored Working Group

Carbon Hot Spot: Drivers and Sensitivities of Large Carbon Uptake in Western Boundary Currents

Abstract

The goal of this SCOR working group is to develop an interdisciplinary and international research community that will facilitate better understanding and awareness of the role that Western Boundary Currents (WBCs) play in climate and anthropogenic carbon dioxide (CO_2) sequestration. Understanding the drivers and sensitivities of carbon uptake in WBCs, as well as the associated climate feedbacks, requires collaboration between physical and chemical oceanographers, who have traditionally worked independently of each other. This international group of researchers will include observationalists and modelers from the chemical and physical oceanography communities who share the common goal of improving climate models through enhanced dynamical understanding of ocean processes. We will achieve this goal by organizing annual meetings, producing a review article, and coordinating a field program and pilot study called Carbon Hot Spot in the Kuroshio Extension region. These activities will culminate in a Chapman Conference on "Improving climate model physical-biogeochemical interactions in Western Boundary Currents."

Scientific Background and Rationale

The ocean is responsible for absorbing nearly a quarter of the anthropogenic carbon emitted into the atmosphere each year, making it an essential component of the climate system that has a damping effect on modern climate change. However, the amount of ocean carbon uptake estimated from climate projections performed with coupled climate models can vary by as much as 29% [Frölicher et al., 2014]. The reasons for these differences are not clear, but the models tend to vary in their representation of lateral mixing by mesoscale eddies, which has been shown to play a significant role in oceanic carbon uptake [Gnanadesikan et al., 2015]. WBC regions are the most eddy-rich locations in the ocean, making them particularly relevant to the study of ocean carbon uptake and storage. Due to these characteristics, the focus of our working group is to better understand physical-biogeochemical interactions and reduce model biases in these eddy-rich WBCs.

WBC regions exhibit intense sea-to-air heat loss, $\mathcal{O}(1000 \text{ W m}^{-2})$, during winter, in connection with cold-air outbreaks. Atmospheric circulation feedback mechanisms associated with this heat exchange have important impacts on the jet stream path, which affect regional climate downstream as well as the formation of Subtropical Mode Water (STMW). Mode waters are thick water masses of nearly constant temperature that form during winter from convective cooling and mixing at the ocean surface, which deepens the mixed layer and increases its thickness. Mode waters have been observed on the equatorward side of all WBCs and their formation accounts for a majority of the anthropogenic CO_2 sequestration that occurs outside of the polar deep-water-formation regions [Sabine et al., 2004]. Figure 1A shows the global pattern of annual net sea-air CO_2 flux and clearly displays the significant role of WBC regions in annual ocean carbon uptake. Although this spatial pattern is well resolved, there are still many open questions about what processes drive the formation and long-term evolution of mode waters, and how this relates to ocean carbon transport and storage. In order to adequately make and understand regional and future climate projections on decadal time scales and longer, it is pivotal that we characterize the drivers of mode water formation and determine how variability in these processes influence carbon and biogeochemical cycling.

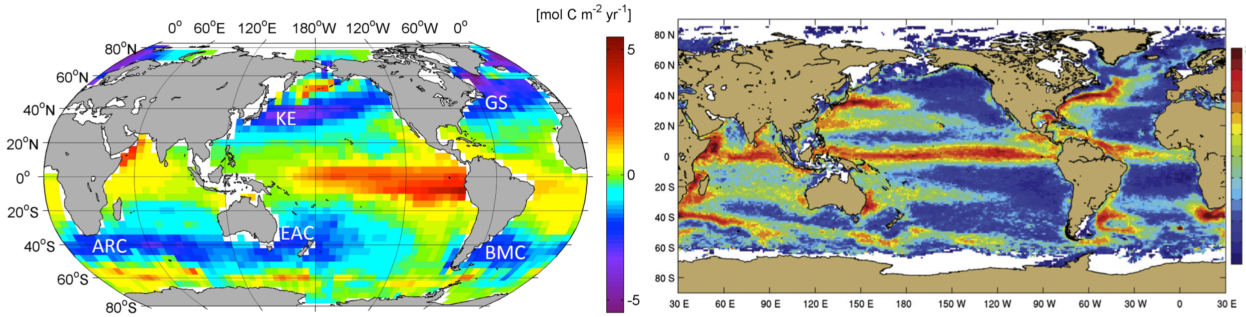

Figure 1: (**A**) Global maps of sea surface annual net sea-air CO_2 flux in units of mol m^{-2} yr^{-1} referenced to year 2000. Negative values indicate net ocean CO_2 uptake. KE = Kuroshio Extension, GS = Gulf Stream, ARC = Agulhas Return Current, EAC = East Australian Current, BMC = Brazil/Malvinas Confluence. Adapted from Figure 5 in [Park et al., 2010]. (**B**) Global map of eddy kinetic energy in units of cm^2 s^{-2} from surface drifters. Figure 14.16 in [Talley et al., 2011].

WBC regions are characterized by the highest eddy kinetic energy in the global ocean (Fig. 1B). One intriguing example of physical-biogeochemical interaction in a WBC comes from the North Pacific Ocean; the Kuroshio Extension (KE). The KE exhibits a clear bimodality in its meandering state within the first 1000 km east of Japan [Qiu and Chen, 2005] and it has been hypothesized that variability in the KE jet modulates the volume of North Pacific Subtropical Mode Water (NPSTMW) formation [Qiu et al., 2007, Cerovecki and Giglio, 2016, Rainville et al., 2014]. In addition, Qiu et al. [2007] argue that year-to-year NPSTMW variability is not correlated with atmospheric forcing, but rather the "dynamic state" of the Kuroshio Extension. More recently covariability in biogeochemistry has been linked with these trends in NPSTMW formation [Oka et al., 2015] and surface chlorophyll [Lin et al., 2014], which has important implications for interannual variability in and future projections of carbon sequestration.

Global climate models are routinely run in a configuration where eddies are parameterized. The results of Gnanadesikan et al. [2015], using a single model, show significant sensitivity in ocean carbon uptake to the parameterization of mesoscale eddy lateral mixing. The sensitivity found in their single model is remarkably similar to the 29% spread seen across climate models in Frölicher et al. [2014], providing further evidence that accurate eddy parameterizations are needed. When models are run in a configuration that explicitly resolves mesoscale eddies, they tend to show better agreement with observations. For example, the Kuroshio Extension bimodality is not present in coarse resolution models, but emerges when mesoscale eddies are resolved [Bishop et al., 2015]. New theories regarding mode water formation and variability have also shed light on the importance of eddies [Deremble and Dewar, 2013]. Climate models that include biogeochemistry are still relatively new and rely on parameterizations of eddy physical-biogeochemical interaction. Due to computational costs, the research community is more than a decade away from routinely resolving mesoscale eddies, and even further away from resolving submesoscale eddies. Therefore it is imperative that researchers better understand the physical-biogeochemical interactions in and around eddies to ensure the best possible parameterizations in climate models.

In the past decade there have been three major field programs in WBCs focusing on the physics:

The Kuorshio Extension System Study (KESS) in the Kuroshio Extension, CLIvar MOde Water Dynamic Experiment (CLIMODE) in the Gulf Stream, and the Agulhas Current Time-Series (ACT) experiment in the Agulhas current. Each of these efforts highlight the importance of extended time series that resolve mesoscale and submesoscale eddies and their order one importance in these systems. The next step in advancing our understanding of WBCs and their role in carbon cycling and climate change, is to link the physical dynamics with the biogeochemical processes that are fundamentally coupled to them. In addition to measurements for estimating air-sea heat, moisture, and momentum fluxes (e.g. wind speed and direction, air and sea surface temperature, humidity, solar and longwave radiation, precipitation, barometric pressure) as well as physical ocean parameters (e.g. temperature, salinity, and near-surface currents), the NOAA Kuroshio Extension Observatory (KEO) moored buoy[1] has been measuring surface ocean and atmosphere partial pressures of CO_2 (pCO_2) since 2007 and surface ocean pH since 2011. Most importantly, KEO is the only buoy making biogeochemicaly relevant measurements in a WBC region.

Observations of sea surface pCO_2 at the KEO mooring between 2007 and 2014 were used by Fassbender [2014] to quantify the annual biological export of organic and inorganic carbon from the ocean surface to the interior using a mixed layer carbon budget approach. This approach was also applied to seven years of sea surface pCO_2 observations from the NOAA Ocean Station Papa (OSP) mooring located in the eastern subarctic North Pacific [Fassbender et al., 2016a]. Results from this work indicate that the annual export of organic carbon, commonly referred to as net community production (NCP), is almost twice as large at KEO as at OSP. The ability of the KEO region to support significantly higher biological productivity is primarily the result of sufficienct iron supply from the Asian continent coupled with seasonal replenishment of mixed layer nutrients (including iron) caused by deep winter mixing during mode water formation [Yasunaka et al., 2013]. Subsequent shoaling of the mixed layer depth in spring results in a massive spring bloom that exhausts all nutrients within a few months [Fassbender, 2014, Fassbender et al., 2016b]. The maximum depth of winter mixing coupled with the balance between the rate of mixed layer shoaling and light availability fundamentally controls the amount of nutrients phytoplankton can utilize before seasonal stratification is complete. Further productivity may be supported by eddy-induced mixing events; however, direct evidence is lacking due to the paucity of observations.

The tight link between biogeochemical cycling and physical mixing processes in the KE region makes this the prime location to study the interplay of physics, chemistry, and biology. The biggest challenge in resolving a modern baseline for biogeochemical cycling in this region and other WBCs is the inability to resolve vertical and horizontal chemical gradients in physical and chemical parameters in real time within dynamic eddy fields. As a result, there are many unknowns regarding how ocean warming and acidification may influence biogeochemical cycling in these important carbon sink regions. Thus, a coordinated effort is needed to quantify the impact of mesoscale and submesoscale eddies on ocean carbon cycling as well as the biological response times to these features in WBC regions.

This working group will build upon past studies of physical and chemical processes in WBCs and create a community of diverse researchers that will engage in international interdisciplinary climate science. One of the main goals of this working group is to plan and conduct a field program near KEO to better understand the role of ocean eddies in upper ocean carbon transformations and provide guidance to the modeling community on how best to parameterize these key process interactions in climate models.

[1] http://www.pmel.noaa.gov/co2/story/KEO

Terms of Reference

The specific goals of our proposed working group are:

1. *Workshop*: Organize a workshop to coordinate physical and chemical oceanographic research on this topic and foster new collaborations. The goals of the workshop will be to synthesize current research activities related to the topic, develop future initiatives, identify strategic collaborations, and determine how best to monitor the WBC systems to improve ocean modeling of biogeochemistry.
2. *Panel Guidance*: This working group will determine how best to monitor CO_2 fluxes in all WBCs and give guidance to CLIVAR panels based on results from the field/pilot study.
3. *Review Paper*: A review paper will be written for publication in an open access peer-reviewed journal that will showcase the importance of WBC regions in carbon sequestration and climate.
4. *Field/Pilot Study*: Plan and conduct a field/pilot study in the Kuroshio Extension region near the KEO surface mooring using autonomous instrumentation in 2018. The goals of this field program will be to better understand the role of eddies in biogeochemical cycling and annual carbon sequestration in WBCs. This study will benefit any future WBC experiment and modeling exercise to see what scales are needed to be resolved to adequately simulate carbon budgets.

List of Products

1. Kick-off article in EOS or BAMS.
2. Review paper in a peer-reviewed open access journal
3. CLIVAR Report on recommendations for future and continuous monitoring of the WBC regions targeting physical and biogeochemical observations.
4. Chapman Conference on "Improving climate model physical-biogeochemical interactions in Western Boundary Currents."

Timeline

The working group anticipates three years of funded support to fulfill the terms of reference. The first course of action will be to put together a kick-off article to announce the group to the greater community in either EOS or BAMS in hopes of attracting other scientists conducting research related to the working group efforts.

Meeting 1

The first working group meeting will take place in April 2017, in conjunction with the IOC/WESTPAC Open Science Meeting in Qingdao, China. Member Xiaopei Lin will be submitting a proposal for a session on WBCs at this meeting. The meeting foci will be on:

- Putting together a review article.
- Planning of Field/Pilot study to take place in winter 2018 in coordination with OMIX/AIKEC experiments.
- Discussing strategies for observations in other WBCs.

Carbon Hot Spot

In between meeting 1 and 2 the Carbon Hot Spot Field/Pilot study will take place tentatively from December 2017–May 2018 during the winter to summer transition encompassing the spring bloom.

Meeting 2

The second working group meeting will take place in conjunction with the 2018 Ocean Sciences meeting to take place in Portland, OR. This meeting will focus on:

- A status update of the Carbon Hot Spot Field/Pilot study in progress.
- Final discussion of the review article to be submitted.
- Plan for Chapman Conference proposal to be submitted a couple months following the meeting.

Meeting 3

A third meeting will take place in conjunction with EGU in summer 2018. This meeting will focus on:

- Preliminary results from the Carbon Hot Spot Field/Pilot study.
- Begin drafting a CLIVAR report for guidance on future observational efforts in all WBCs as well as a CLIVAR process study proposal.
- Final planning for Chapman Conference to take place in winter/spring 2019.

Chapman Conference

The working group will culminate in the Chapman Conference. This conference will bring together observationalists and modelers with expertise in physical and chemical oceanography. The meeting will focus on the status of the research topic, include discussion of new insights gained from Carbon Hot Spot, address how to improve modeling efforts based on Carbon Hot Spot, and determine future directions and collaborations beyond the SCOR working group.

Collaboration and Capacity Building

This working group will collaborate and coordinate with Dr. Lin's research group (also a member of this working group) at the Ocean University of China on the Air-Sea Interaction in the Kuroshio Extension and its Climate impact (AIKEC) experiment. A cruise will take place in early summer 2017 as part of the AIKEC experiment. Lin has offered this cruise as an opportunity for collaborated observations. This working group will also build stronger collaborations with the Ocean Mixing Processes Impact on Biogeochemistry, Climate and Ecosystem (OMIX[2]) experiment. Dr. Oka (also a member of this working group) is involved with OMIX. It is a coordinated effort amongst the Japanese to understand physical-biogeochemical interactions caused by tidal-induced diapycnal mixing in the upstream Oyashio and Kuroshio. Both AIKEC and OMIX will span the SCOR Working Group period. In order to build further collaboration and capacity building, we will invite early career scientists to the Chapman conference and bridge the international community by building mentor-mentee relationships across disciplines, institutions, and countries.

[2]http://omix.aori.u-tokyo.ac.jp/en/

Chairs and Working Group Members

Members

Name	Gender	Affiliation	Expertise
Stuart Bishop (co-chair)	M	NCSU (USA)	PO
Andrea Fassbender (co-chair)	F	MBARI (USA)	BGC
Kitack Lee	M	Pohang U. of Sci. and Tech. (S. Korea)	BGC
Geun-Ha Park	F	KIOST (S. Korea)	BGC
Xiaopei Lin	M	Ocean U. of China (China)	PO
Ryuichiro Inoue	M	JAMSTEC (Japan)	PO
Eitarou Oka	M	U. of Tokyo (Japan)	PO
Pedro Monteiro	M	SCIR (S. Africa)	BGC
Debby Ianson	F	DFO (Canada)	BGC
Roberta Hamme	F	University of Victoria (Canada)	BGC

Associate Members

Name	Gender	Affiliation	Expertise
Adrienne Sutton	F	JISAO (USA)	BGC
Meghan Cronin	F	NOAA PMEL (USA)	PO

Working Group Contributions

Dr. Stuart Bishop (co-chair): Expertise in WBC dynamics with an emphasis towards understanding mesoscale and submesoscale eddies and their role in ocean circulation. Expertise in using/obtaining observational and modeling data sets using autonomous ocean instrumentation and high-resolution modeling respectively.

Dr. Andrea Fassbender (co-chair): Expertise in quantifying the processes involved in regional biogeochemical cycling to better understand how ocean warming and acidification may influence the drivers of carbon transport and storage in the ocean. She approaches this research by combining ship, mooring, float, and satellite observations in addition to developing new instrumentation for carbon cycle research with the goal of characterizing modern baselines for biogeochemical cycling throughout the ocean.

Dr. Kitack Lee: Expertise in marine carbon cycle dynamics and biogeochemical cycling. His work ranges from the regional to global scale and addresses important linkages between ocean biology and chemistry now and under future climate change scenarios.

Dr. Geun-Ha Park: Expertise in the quantification of anthropogenic CO_2 within the water column and research for changes in sea-air CO_2 fluxes. She recently found unusually high surface partial pressure of CO_2 last summer in the area where the formation of STMW occurs and is trying to figure out the reason for it.

Dr. Xiapoei Lin: Expertise wtih combining observation and numerical simulations, Xiaopei will focus on the multiscale air-sea interaction in the WBC region and its climate impact to improve the understanding of ocean and climate dynamics.

Dr. Ryuichiro Inoue: Expertise working on data taken by Argo floats with DO sensor, BGC mooring, and shipboard measurements to understand biogeochemical responses to a cyclonic eddy in the oligotrophic subtropic ocean. He will analyze floats and glider data to understand impacts of mixing and meso- and submesoscale processes on biogeochemical properties in WBC.

Dr. Eitarou Oka: Expertise working to understand decadal variability of mode waters in the North Pacific by using satellite products, Argo floats and shipboard measurements. He will analyze floats and shipboard data to understand impact of those physical oceanographic conditions on variability of biogeochemical properties.

Dr. Pedro Monteiro: CO_2 work to understand how and why ocean biogeochemistry of oxygen and carbon adjust to climate variability. The use of numerical modeling as experimental platforms to understand scale sensitivities of coupled physics and biogeochemical processes.

Dr. Debby Ianson: Expertise in evaluating interdisciplinary oceanographic problems that are pertinent to climate variability over a variety of time-scales throughout unique oceanic environments. She approaches these problems by integrating traditionally disconnected disciplines using modeling as a tool supplemented by field work to identify crucial aspects within complex systems through model development and validation.

Dr. Roberta Hamme: Dr. Hamme's group makes measurements of dissolved gases and uses them to elucidate the biological and physical mechanisms that isolate carbon from the surface ocean and atmosphere. She holds a Canada Research Chair in Ocean Carbon Dynamics and will contribute her expertise on gas exchange processes and productivity rate measurements.

Appendix: Key Publications

Stuart Bishop (co-chair)

1. Bishop, S.P. and D.R. Watts (2014). Rapid eddy-induced modification of Subtropical Mode Water during the Kuroshio Extension System Study. J. Phys. Oceanogr., 44, 1941-1953.

2. Bishop, S.P. and F.O. Bryan (2013). A comparison of mesoscale eddy heat fluxes from observations and a high-resolution ocean model simulation of the Kuroshio Extension. J. Phys. Oceanogr., 43, 2563-2570.

3. Small, J.R., J. Bacmeister, D. Bailey, A. Baker, S.P. Bishop, F.O. Bryan, J.M. Caron, J. Dennis, P. Gent, H.-M Hsu, M. Jochum, D. Lawrence, E. Munoz, P. diNezio, T. Scheitlin, B. Tomas, J. Tribbia, Y.-H. Tseng, and M. Vertenstein (2014). A new synoptic scale resolving global climate simulation using the Community Atmosphere Model. J. Adv. Model. Earth Syst., 6, 1065-1094.

4. Bishop, S.P. (2013). Divergent eddy heat fluxes in the Kuroshio Extension at 144°-148°. Part 2: Spatiotemporal variability. J. Phys. Oceanogr., 43, 2416-2431.

5. Bishop, S.P., F.O. Bryan, and R.J. Small (2015). Bjerknes-like compensation in the wintertime North Pacific. J. Phys. Oceanogr., 45, 1339-1355.

Andrea Fassbender (co-chair)

1. Fassbender, A. J., C. L. Sabine, and M. F. Cronin, Net community production at the Kuroshio Extension Observatory and its role in regional carbon cycling. In progress.

2. Fassbender, A. J., C. L. Sabine, and M. F. Cronin (2016), Net community production and calcification from seven years of NOAA Station Papa Mooring measurements, Global Biogeochem. Cycles, doi:10.1002/2015GB005205.

3. Fassbender, A. J., C. L. Sabine, N. Lawrence-Slavas, E. H. De Carlo, C. Meinig, and S. Maenner Jones (2015), Robust Sensor for Extended Autonomous Measurements of Surface Ocean Dissolved Inorganic Carbon, Environ. Sci. Technol., 49(6), 3628-3635, doi:10.1021/es5047183.

4. Fassbender, A. J. (2014), New approaches to study the marine carbon cycle. PhD dissertation, University of Washington. Proquest, 1/11/2016, http://hdl.handle.net/1773/27552.

5. Sabine, C. L. et al. (2013), Surface Ocean CO_2 Atlas (SOCAT) gridded data products, Earth Syst. Sci. Data, 5(1), 145-153, doi:10.5194/essd-5-145-2013.

Kitack Lee

1. Ko. Y.-H., K. Lee, K.-H. Eom, I. Han (2016), Organic alkalinity produced by phytoplankton and its effect on computations of ocean carbon parameters, Limnology and Oceanography, in press.

2. Kim, T.-W., Park, G.-H., Kim, D.-S., K. Lee, R. Feely, F. Millero (2015), Seasonal variations in the aragonite saturation state in the upper open-ocean waters of the North Pacific Ocean, Geophysical Research Letters, DOI:10.1002/2015GL063602.

3. Kim, J.-M., K. Lee, K. Shin, E.J. Yang, A. Engel, D. M. Karl, H.-C. Kim (2011), Shifts in biogenic carbon flow from particulate to dissolved forms under high carbon dioxide and warm ocean conditions, Geophysical Research Letters, 38, L08612, doi:10.1029/2011GL047346. [I.F. 2.397].

4. Sabine, C.L., R.A. Feely, N. Gruber, R.M. Key, K. Lee et al. (2004), The oceanic sink for anthropogenic CO2, Science, 305, 367-371. (2004/7/16).

5. Lee, K., D.M. Karl, J.-Z. Zhang, and R. Wanninkhof (2002), Global estimates of net carbon production in the nitrate-depleted tropical and subtropical ocean, Geophysical Research Letters, 29, 13/1-13/4. (2002/10/4).

Geun-Ha Park

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2. Rik Wanninkhof, Geun-Ha Park, Taro Takahashi, Colm Sweeney, Richard A. Feely, Yukihiro Nojiri, Nicolas Gruber, Scott C. Doney, Galen A. McKinley, Andrew Lenton, Corinne Le. Qur, Christopher Heinze, Jrg Schwinger, Heather Graven, and Samar Khatiwala (2013). Global ocean carbon uptake: magnitude, variability and trends, Biogeosciences, 10, 1983-2000, doi:10.5194/bg-10-1983-2013.

3. Masao Ishii, Richard A. Feely, Keith B. Rodgers, Geun-Ha Park, Rik Wanninkhof, Daisuke Sasano, Hiroyuki Sugimoto, Cathy E. Cosca, Shinichiro Nakaoka, Maciej Telszewski, Yukihiro Nojiri, Sara E. MikaloffFletcher, Yosuke Niwa, Prabir K. Patra, Vinu Valsala, Hideyuki Nakano, Ivan Lima, Scott C. Doney, Erik T. Buitenhuis, Olivier Aumont, John P. Dunne, Andrew Lenton, and Taro Takahashi (2014), Air-sea CO_2 flux in the Pacific Ocean for the period 1990-2009, Biogeosciences, 11, 709-734, doi:10.5194/bg-11-709-2014.

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Xiaopei Lin

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5. Xiaohui Ma, Ping Chang, R. Saravanan, Raffaele Montuoro, Jen-Shan Hsieh, Dexing Wu, Xiaopei Lin, Lixin Wu & Zhao Jing (2015), Distant Influence of Kuroshio Eddies on North Pacific Weather Patterns? Scientific Reports 5.

Ryuichiro Inoue

1. Kouketsu, S., H. Kaneko, T. Okunishi, K. Sasaoka, S. Itoh, R. Inoue, and H. Ueno (2015), Mesoscale eddy effects on temporal variability of surface chlorophyll a in the Kuroshio Extension. J. Oceanogr., DOI 10.1007/s10872-015-0286-4.

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Eitarou Oka

1. Oka E., B. Qiu, Y. Takatani, K. Enyo, D. Sasano, N. Kosugi, M. Ishii, T. Nakano, and T. Suga (2015), Decadal variability of Subtropical Mode Water subduction and its impact on biogeochemistry. Journal of Oceanography, 71, 389-400.

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Pedro Monteiro

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Debby Ianson

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1. Hamme, Roberta C., Johanna E. Berry, Jody M. Klymak, and Kenneth L. Denman (2015), In situ O2 and N2 measurements detect deep-water renewal dynamics in seasonally-anoxic Saanich Inlet, Continental Shelf Research, doi:10.1016/j.csr.2015.06.012.

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