Sergio Rossi

SDG 14: Life Below Water

A Machine-Generated Overview of Recent Literature

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Sergio Rossi
University of Salento
Lecce, Italy

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Introduction

In recent years it has been stressed that the problems created by population growth and climate change are so big and of such complexity that we do not have the capacity to address them. We do not react to a cascade of situations that are driving us to absolute collapse for two reasons: (1) The mental short-termism that is inherent in any animal, including the human being, (2) the synergy of factors that act together, not being able to isolate each other to give partial solutions.

In this puzzle, the oceans, after decades of being ignored, seem to take on relevance. The UN launched a plan to draw attention to the role of that 70% mass of water that covers the surface of our planet, finally coming to the conclusion that part of the solution lies in understanding, managing and restoring the oceans. Biodiversity, complexity, and functionality take on relevance in one of the Sustainable Development Goals that aims to improve our oceans. Life Below Water (SDG 14) is one of the goals to be achieved in this desperate decade, in which we are going to have to race to try to save civilization in its many facets. A Decade of the Oceans has been instituted that aims to channel the greatest possible number of initiatives to substantially improve the health of marine habitats, as well as try to mitigate the impact on human communities.

Fisheries, pollution, and urban expansion are some direct issues that are stressing the oceans, but we may have direct (local and regional) solutions to solve them in many cases. However, among all the challenges we face, the most global and complex one to mitigate is climate change. In the oceans, climate change is especially evident, since 93% of the heat absorbed by the earth is concentrated in the water masses that are warming rapidly. Acidification, which is the sister of warming in water masses due to the increase in CO_2 that penetrates and reacts to create slightly less alkaline water, is the other large-scale problem that has a global impact and cannot be controlled locally. Marine organisms suffer these consequences, having to adapt, migrate or disappear. We have created a transition phase to a new unknown state in which some species, habitats and even biomes will prevail while others languish or simply disappear. Understanding, managing and repairing our actions in the oceans has become a very urgent task to solve the problem and understand how long this transition between systems will last.

This book focuses, in seven chapters, on the perspectives and solutions that different research groups offer to try to address problems related to SDG 14: Life Below Water. The different objectives developed in SDG 14 are treated independently, with an attempt to give a global vision of the issues. The mechanism used to select the book's content was through an Artificial Intelligence program, choosing articles related to the topics by means of keywords. The program selected those articles, and those that were not related to the topic or did not focus on SDG 14 were discarded. Obviously, the selection was partial and the entire subject is not covered, but the final product gives a very solid idea of how to orient ourselves to delve deeper into the topic of SDG 14 using published chapters and articles. The AI program itself selected the text of these contributions to show the progress in different topics related to SDG 14. This mode of operation will allow specialists (and non-specialists) to collect useful information for their specific research purposes in a short period of time. At a time when information is essential in order to move quickly by providing concrete answers to complex problems, this type of approach will become essential for researchers, especially for a subject as vast as SDG 14.

Sergio Rossi

Contents

Chapter 1
A Comprehensive Overview of SDG 14: Life Below Water_Final

1.1 Biogeochemical Cycles and Microbial Loop: Pollution and the Effects of Climate Change

Machine generated keywords: acidification, pacific, abundance, ocean acidification, estuarine, sea, plankton, Deepsea, north, group, western, variation, Atlantic, arctic, circulation.

1.1.1 Biogeochemical, Eutrophication, Ocean Circulation

Machine generated keywords: estuarine, arctic, biogeochemistry, storm, dust, assessment, metal, ipcc, baltic, baltic sea, sea, zinc, pacific, north sea, puget.

Simulation of Annual Biogeochemical Cycles of Nutrient Balance, Phytoplankton Bloom(s), and DO in Puget Sound Using an Unstructured Grid Model

https://doi.org/10.1007/s10236-012-0562-4

Abstract-Summary

Results based on 2006 data show that phytoplankton growth and die-off, succession between two species of algae, nutrient dynamics, and dissolved oxygen in Puget Sound are strongly tied to seasonal variation of temperature, solar radiation, and the annual exchange and flushing induced by upwelled Pacific Ocean waters.

Concentrations in the mixed outflow surface layer occupying approximately 5–20 m of the upper water column show strong effects of eutrophication from natural and anthropogenic sources, spring and summer algae blooms, accompanied by depleted nutrients but high dissolved oxygen levels.

S. Rossi, *SDG 14: Life Below Water*,
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The bottom layer reflects dissolved oxygen and nutrient concentrations of upwelled Pacific Ocean water modulated by mixing with biologically active surface outflow in the Strait of Juan de Fuca prior to entering Puget Sound over the Admiralty Inlet.

The effect of reflux mixing at the Admiralty Inlet sill resulting in lower nutrient and higher dissolved oxygen levels in bottom waters of Puget Sound than the incoming upwelled Pacific Ocean water is reproduced.

Introduction

A model study of the Salish Sea was conducted with a focus on the Puget Sound region in an effort to improve our understanding of the annual biogeochemical cycles of nutrient loading and consumption by algal growth and the effects of seasonal variations on primary productivity and dissolved oxygen (DO).

Large quantities of nutrient loads from the Pacific Ocean also enter the Salish Sea through the Strait of Juan de Fuca and enter Puget Sound through tidal exchange flow over the Admiralty Inlet [1].

Based on review of historic current meter records, Ebbesmeyer and Barnes [2] developed a conceptual model of Puget Sound that describes circulation in the main basin of Puget Sound as that in a fjord with deep sills (landward sill zone at Tacoma Narrows and a seaward sill zone at Admiralty Inlet) defining a large basin, outflow through the surface layers, and inflow at depth.

We present the first 3-D water quality model of the entire Salish Sea with a focus on the Puget Sound region.

Model description and configuration

The biogeochemical model selected for use with the FVCOM solution was CE-QUAL-ICM, a 3-D, time variable, integrated-compartment model, developed by the U.S. Army Corps of Engineers for simulating water quality [3].

The use of the carbon cycle as the basis for eutrophication calculations, the ability to include sediment diagenesis, and the use of a finite volume approach were important considerations in selection of CE-QUAL-ICM for the Salish Sea model development with FVCOM.

In CE-QUAL-ICM, all organic matter entering the model domain from the open boundaries and from point sources is tracked directly in the form of dissolved or particulate organic carbon, organic nitrogen, and organic phosphorous.

Linkage of FVCOM hydrodynamic solution with CE-QUAL-ICM was accomplished through the development of a modified code herein referred to as the Unstructured Biological Model (UBM) in which the transport calculations are conducted through the FVCOM framework and biogeochemical calculations are conducted using CE-QUAL-ICM kinetics over the same finite volume mesh, as used in hydrodynamic calculations using a triangular elements.

Salish Sea model setup and calibration

Year 2006 was identified as the most recent data-rich period for salinity, temperature, and water quality (nutrients, phytoplankton, and DO) and selected for the model calibration effort.

Strait of Juan de Fuca boundary nitrate+nitrite concentrations are approximately 0.4 mg/L at depth throughout the year, with concentrations approximately half of this value (0.1–0.2 mg/L) at the surface during the summer.

DO is quite low at depth, 2–4 mg/L throughout the year in waters deeper than 100 m. Initial model setup was conducted using literature values for the model parameters.

For nutrient uptake, general ranges surrounding the estuarine half-saturation constants were tested during the calibration, with the best fit at the upper end of the half-saturation constant range for N and P. The half-saturation constants based on data from 17 species of marine phytoplankton have been reported in the range from 0.001 to 0.144 mg N/L [4, 5].

Results and discussion

One possible explanation for this variation in algal biomass may be temperature variability among the basins with surface waters in the main deeper basins of Puget Sound being a little cooler than the shallow subbasins.

As in the case of nutrients, during autumn months after the summer bloom period, the algal activity also reduces because of the reduced light availability and lower temperatures, and DO concentrations in the surface layer return to their pre-bloom levels.

While DO concentrations at a Puget Sound scale are dominated by the incoming waters from the Strait of Juan de Fuca, it is important to note that DO levels especially in the shallow nutrient limited subbasins, could be affected by smaller scale eutrophication processes and blooms perturbed by local anthropogenic discharges.

Conclusion

While the current model calibration is suitable for addressing the broad water quality management question of whether human sources of nutrients in and around Puget Sound are significantly affecting water quality and, if so, how much nutrient reduction is necessary to reduce human impacts in sensitive areas, targeted future improvements and refinements to the model are ongoing.

The model predictions, particularly in the deeper waters of Puget Sound, are strongly dependent on the Pacific Ocean water quality (at the Neah Bay boundary in the Strait of Juan de Fuca) and the quality of inflow of water from Georgia Straits (affected correspondingly by the boundary near Johnstone Strait).

Despite these limitations, the model reproduces overall seasonal algal bloom dynamics and DO levels in Puget Sound resulting from exchanges with the Pacific Ocean and nutrient loads from natural and human sources within the basin.

Acknowledgements

A machine generated summary based on the work of Khangaonkar, Tarang; Sackmann, Brandon; Long, Wen; Mohamedali, Teizeen; Roberts, Mindy. 2012 in Ocean Dynamics.

Reconstructing the Development of Baltic Sea Eutrophication 1850–2006

https://doi.org/10.1007/s13280-012-0318-x

Abstract-Summary

A comprehensive reconstruction of the Baltic Sea state from 1850 to 2006 is presented: driving forces are reconstructed and the evolution of the hydrography and biogeochemical cycles is simulated using the model BALTSEM.

BALTSEM shows a delayed response to the massive load increase with most eutrophic conditions occurring only at the end of the simulation.

The simulation indicates that no improvement in water quality of the Baltic Sea compared to its present state can be expected from the decrease in nutrient loads in recent decades.

Extended:

This has huge implications for management, because if this is true, all efforts taken to reduce nutrient loads up to now basically resulted in maintaining the status quo and that additional action is needed in order to improve water quality.

Introduction

Human-induced pressures on the Baltic Sea ecosystem have significantly accelerated during the twentieth century, especially in terms of anthropogenic nutrient loading (e.g., [6]), leading to increased nutrient concentrations (e.g., [7]), increased summer cyanobacteria blooms (e.g., [8]) and expanding hypoxia (e.g., [9]).

To the direct anthropogenic impact on the Baltic Sea ecosystem, climatic conditions show strong and partly unprecedented changes in recent decades (e.g., [10]) which, combined with anthropogenic pressures, have been associated with an ecosystem-wide regime shift in higher trophic levels in the Baltic proper (e.g., [11]).

The combined effects of changed trophic and climatic conditions have raised concerns about the Baltic Sea ecosystem being pushed towards its natural limits [12].

There are, in addition, practical needs for a good description of the pre-industrial state of the Baltic Sea ecosystem, i.e., the implementation of recent European Union legislations—the Water Framework Directive and Marine Strategy Framework Directive and the HELCOM Baltic Sea Action Plan.

Materials and Methods

The hydrodynamic part of the model is forced by 3-hourly weather parameters: winds, temperature, humidity, cloudiness, pressure, and precipitation, by daily average sea level in Kattegat, river runoff and stratification at the Skagerrak boundary.

As the spatial resolution of the various data sets differ (total catchment, basins, individual rivers), the variability of the reconstructed runoff changes with time.

For 1970–2006, monthly time-series of the atmospheric nitrogen deposition to each basin were compiled at the Baltic Nest Institute [13] combining estimates based on measurements and modeling.

The reconstruction of the time-series for 1850–1970 was made by a linear interpolation between a few selected “reference” years: 1850, 1900, 1925, 1950, 1960, and 1970, for which atmospheric deposition was estimated from available data.

Results

The relative increase in phosphorus loads has been much larger than that for nitrogen and consequently the nitrogen/phosphorus molar ratio in the nutrient input to the Baltic decreased from about 68 to 37 between 1850 and 1980.

Surface nitrate concentrations seem to level off after the peak in load passed in the early 1980s in all basins, while phosphate continues to increase, especially in Gulfs of Riga and Finland.

Around 1900, phosphorus and nitrogen uptake were about 10 and 3.5 times larger than the load, but around 2000 these factors increased to 23 and 8.5.

After 1980 external nutrient loads started to decrease, but the phosphorus and nitrogen outflux from the sediments continued increasing and compensated the load reduction.

Due to the recent decrease in loads and the continued increase in the sediment pool, the sediment phosphorus pool was approximately 35 times the load by 2000.

Discussion

It is tempting to assume that biogeochemical oxygen consumption is underestimated in the early part of the simulation either due to underestimation of reconstructed loads, simulated primary production and sedimentation, or from possible shortcomings in the parameterization of deep-water oxygen consumption in a more oligotrophic Baltic Sea.

The sensitivity of the model was therefore explored with an experiment in which oxygen concentrations were artificially prohibited to drop lower than a minimum of 5 mL L^{-1} throughout the simulation (not shown), and indeed the DIN/DIP ratio was then more constant in the last decade, primarily because winter DIN concentrations were 50% higher in the surface of Baltic proper, but also winter DIP concentrations were somewhat lower.

The continued deterioration in water quality of the major Baltic Sea basins in recent years is clearly caused by the delayed response in primarily the phosphorus cycles.

Conclusions

The very good agreement of modeled and observed water temperatures gives high confidence in the reconstruction and the model simulation.

The long- and short-term salinity and temperature variations that are well described in the Baltic Sea basins shows that river runoff, at least after about 1900, and sea-level reconstructions, together with the high resolution atmospheric forcing (HiResAFF), are of sufficient quality to drive the physical processes in BALTSEM.

The BALTSEM simulation plausibly describes the evolution of nutrient concentrations in the early part of the simulation and reproduces very well the development in recent years.

The simulation gives clear indication that the nutrient load reconstructions are reasonable.

Acknowledgement

A machine generated summary based on the work of Gustafsson, Bo G.; Schenk, Frederik; Blenckner, Thorsten; Eilola, Kari; Meier, H. E. Markus; Müller-Karulis, Bärbel; Neumann, Thomas; Ruoho-Airola, Tuija; Savchuk, Oleg P.; Zorita, Eduardo. 2012 in Ambio.

Modelling Estuarine Biogeochemical Dynamics: From the Local to the Global Scale

https://doi.org/10.1007/s10498-013-9218-3

Abstract-Summary

This manuscript reviews recent developments in the modelling of estuarine biogeochemical dynamics.

The first part provides an overview of the dominant physical and biogeochemical processes that control the transformations and fluxes of carbon and nutrients along the estuarine gradient.

The most important biogeochemical processes are then discussed in the context of key biogeochemical indicators such as the net ecosystem metabolism (NEM), air–water CO_2 fluxes, nutrient-filtering capacities and element budgets.

We show how a combination of RTM and high-resolution data can help disentangle the complex process interplay, which underlies the estuarine NEM, carbon and nutrient fluxes, and how such approaches can provide integrated assessments of the air–water CO_2 fluxes along river–estuary–coastal zone continua.

Trends in estuarine biogeochemical dynamics across estuarine geometries and environmental scenario are explored, and the results are discussed in the context of improving the modelling of estuarine carbon and CO_2 dynamics at regional and global scales.

Introduction

The quantitative significance of the estuarine bioreactor as a regulator of land–ocean carbon and nutrient fluxes or global atmospheric CO_2 concentrations remains poorly constrained (e.g. [14–16]).

Even today, only a few modelling studies incorporate the full suite of interacting physical, biological and chemical processes controlling the coupled transformations of carbon and nutrients along an estuarine gradient (e.g. [17–19]).

Our ability to assess the quantitative role of the estuarine environment for global biogeochemical cycles and greenhouse gas budgets, as well as its response to ongoing land-use and climate changes, requires comparative studies that cover a large range of different systems, thus enabling the identification of global patterns [20].

The development of scaling approaches including new modelling tools that extrapolate knowledge from well-studied to data-poor estuarine systems is required to advance our quantitative understanding of their role in the global climate system.

Estuaries Within the Context of the Land–Ocean Continuum

Although estuaries may comprise coastal environments as diverse as deltas, lagoons and fjords, our analysis exclusively focuses on tidal systems due to their intense biogeochemical processing and long residence times (e.g. [21]).

In alluvial estuaries, the tidal discharge directly depends on the channel size.

A high river discharge typically induces a prismatic channel with long convergence lengths, while a large tidal range results in a funnel-shaped estuary with short convergence lengths.

The Scheldt and the Delaware are typical tidally dominated, funnel-shaped alluvial estuaries, occasionally referred to as marine-dominated estuaries [22], with a cross-section convergence length of only 26 and 41 km and a width convergence length of 28 and 42 km, respectively [23].

At the other end of the spectrum of shapes, the Solo or the Lalang are typical examples of fluvial-dominated, prismatic alluvial estuaries that are also referred to as river-dominated estuaries [22].

Anthropogenic point sources of reactive nutrients and labile organic carbon can have significant effects on the biogeochemistry of rivers and estuaries [24, 25].

The Estuarine Filter

The benthic biogeochemical dynamics often reveal a marked two-dimensional pattern (e.g. [26]) as a result of widely varying local hydrodynamic conditions between shallow intertidal flats, characterized by conditions of low kinetic energy and net SPM deposition, and deep tidal channels where net erosion prevails.

Such dynamics have been reported for numerous estuaries (e.g. [27, 28]) and have important implications for the quantification of biogeochemical processes and export fluxes of C and nutrients.

Estuaries receive a complex mix of organic matter from very different sources as reflected by their characteristic $\delta^{13}C$ and $\Delta^{14}C$ profiles between the river and marine end-members (e.g. [29]).

The estuarine-filtering capacity is another important Estuarine Biogeochemical Indicator and is a dimensionless number defined as the ratio of the net consumption of a specific element integrated over the entire estuarine domain during a given time interval to its total input (e.g. [30–33]).

Quantifying the Estuarine Filter

Studies have shown that the use of time-averaged concentrations, the assumptions of a well-mixed box and steady-state residual flow may result in large errors in estimates of estuarine transformation rates and export fluxes (e.g. [32, 34, 35]).

The quantitative assessment of the estuarine carbon and nutrient fluxes is further complicated by the complex interplay of estuarine and coastal processes at the transition between these two environments (e.g. [33]).

The estuarine pH is highly sensitive to many reaction processes and is thus a very good indicator of the model's ability to resolve the underlying biogeochemical dynamics.

Low reaction rates are nevertheless simulated in the lower estuary, indicating that the reduced species CH_2O (and ammonium) are also efficiently oxidized within the prismatic estuarine system.

Simulation results thus emphasize the importance of the interaction timescales between biogeochemical and transport processes and, hence, between estuarine biogeochemistry and geometry.

Conclusion and Outlook

One of the biggest future challenges in estuarine biogeochemical research will be to develop suitable quantitative approaches that allow assessing the role of the estuarine biogeochemical reactor for global biogeochemical cycles and climate, as well as its response to climate and land-use changes at both a global scale and over climate relevant timescales.

Upscaling strategies that allow incorporating the estuarine filter in ESMs at low computational costs need to be developed, in particular to separate the natural and anthropogenic contributions to the global estuarine carbon fluxes and their future response to climate and environmental change.

Our ability to understand the role of the land–ocean continuum for global biogeochemical cycles and climate will critically depend on a better quantitative understanding of the estuarine biogeochemical dynamics on a global scale.

Acknowledgement

A machine generated summary based on the work of Regnier, Pierre; Arndt, Sandra; Goossens, Nicolas; Volta, Chiara; Laruelle, Goulven G.; Lauerwald, Ronny; Hartmann, Jens. 2013 in Aquatic Geochemistry.

Microbial Biogeography of the North Sea During Summer

https://doi.org/10.1007/s10533-012-9783-3

Abstract-Summary

The microbial community compositions and physicochemical conditions of the different water masses in the North Sea, a biologically productive sea on the northwestern European continental shelf, were studied during two summer cruises, in order to provide detailed baseline data for this region and examine its microbial biogeography.

For each cruise the stations were clustered according to their physicochemical characteristics and their microbial community composition.

The largest cluster, which covered most of the central and northern North Sea, consisted of stations that were characterized by a thermally stratified water column and had low chlorophyll a autofluorescence and generally low microbial abundances.

Despite the complex and dynamic hydrographic nature of the North Sea, the consistent distinctions in microbiology between these different hydrographic regions during both cruises illustrate the strong links between the microbial community and its environment, as well as the possibility to use microorganisms for long-term monitoring of environmental change.

Extended:

Despite the complex and dynamic hydrographic nature of the North Sea, it was possible to distinguish a number of biogeographical regions, based on the distributions of the main components of the microbial community (phytoplankton, HP and viruses).

The North Sea is prone to future changes in a range of environmental parameters, and monitoring its microbial abundances and activity will help us to anticipate how microbial systems, and thus biogeochemical cycles, will shift in a changing world.

Introduction

These shifts were related to temporary changes in physicochemical parameters associated with incursions of North Atlantic Ocean waters into the North Sea, rather than with global trends in atmospheric oscillation or anthropogenic perturbations [36].

Despite their potential importance, the responses of the microbial community to changing environmental conditions in the North Sea are still largely unknown.

Compared to previous studies that focused on a discrete region within the North Sea or only one component of the microbial community, our study is more comprehensive, as at each station phytoplankton, bacteria and virus communities were sampled alongside a range of physicochemical metadata parameters.

As the North Sea is highly prone to both short-term and long-term environmental changes, monitoring the microbial community and activity in this region will help us to anticipate how microbial systems, and thus biogeochemical cycles, will shift in a changing world.

Materials and methods

Samples for heterotrophic prokaryotes and viruses were fixed to a final concentration of 0.5% with glutaraldehyde (25% stock solution, EM-grade) for 30 min, after which they were flash frozen in liquid nitrogen and stored at −80 °C until analysis in the home laboratory.

Heterotrophic prokaryote (HP) abundances were determined using a FACSCalibur flow cytometer, after the thawed samples were diluted in Tris–EDTA buffer (10 mM Tris–HCl and 1 mM EDTA, pH 8.0), and stained with the nucleic acid-specific green fluorescent dye SYBR Green I (Molecular Probes Inc., Eugene, USA) to a final concentration of 1×10^{-4} of the commercial stock for 15 min in the dark at room temperature [37].

Results

For both cruises the largest cluster (CO E3 and MV E1; yellow symbols) is formed by stations representative of the deeper northern and central North Sea, which has T–S curves typical of thermally stratified waters (surface temperature 15–16 °C decreasing to 7 °C; and salinity increasing from 34.0 to 35.5).

Cluster CO E2 (light blue symbols) is formed by stations in the southern North Sea, which are influenced by Continental Coastal water (not sampled during MV), and have temperatures of 17–18 °C and salinities of 34.9–35.2 in the south, and temperatures of 16–18 °C and salinities of 33.2–34.8 towards the north.

The lowest relative contributions of HDNA-HP were observed for the north-northwestern region of the study area (i.e. MV stations 12, 13 and CO stations 19, 25 and 35–37), while the highest were observed in the Skagerrak and southern Norwegian Coastal water (>50%), and in the southern North Sea (60–70%).

Discussion

During both cruises the largest microbial cluster (CO M1 and MV M1) was defined by low chlorophyll a autofluorescence, which resulted largely from low nanoeukaryote abundances in the nutrient-limited waters of the central and northern North Sea.

The consistent distinction between North Sea, North Atlantic-influenced, and Norwegian Coastal/Skagerrak waters during both cruises illustrates the strong links between the microbial community and their environment, as well as the possibility to use micro-organisms to monitor environmental change.

Although the similar results obtained from both cruises suggest that a limited number of stations would suffice for monitoring the microbiology of the entire North Sea, their differences also highlight that it is essential to include the adjacent water masses (e.g. the eastern North Atlantic and English Channel during the MV cruise and the Skagerrak and German Bight during the CO cruise) in order to gain more confidence in defining environmental and microbial subdivisions of this complex region.

Acknowledgement

A machine generated summary based on the work of Brandsma, Joost; Martínez, Joaquin Martínez; Slagter, Hans A.; Evans, Claire; Brussaard, Corina P. D. 2012 in Biogeochemistry.

Skill Assessment of Three Earth System Models with Common Marine Biogeochemistry

https://doi.org/10.1007/s00382-012-1362-8

Abstract-Summary

We have assessed the ability of a common ocean biogeochemical model, PISCES, to match relevant modern data fields across a range of ocean circulation fields from three distinct Earth system models: IPSL-CM4-LOOP, IPSL-CM5A-LR and CNRM-CM5.1.

The simulated vertical distribution of biogeochemical tracers suffer from biases in ocean circulation and a poor representation of the sinking fluxes of matter.

Differences between upper and deep ocean model skills significantly point to changes in the underlying model representations of ocean circulation.

IPSL-CM5A-LR and CNRM-CM5.1 poorly represent deep-ocean circulation compared to IPSL-CM4-LOOP degrading the vertical distribution of biogeochemical tracers.

These improvements result in a better representation of large-scale structure of biogeochemical fields in the upper ocean.

Further improvements in the representation of the ocean mixed-layer and deep-ocean ventilation are needed for the next generations of models development to better simulate marine biogeochemistry.

Extended:

We have assessed three Earth system models with a common marine biogeochemistry: IPSL-CM4-LOOP, IPSL-CM5A-LR and CNRM-CM5.1.

Introduction

Earth system models are key to the IPCC assessment process but present multiple differences in term of resolution, subgrid-scale physics, and biogeochemical components.

When comparing ocean carbon models it is difficult to disentangle the main causes for disagreement because of their many differences, including resolution, parametrizations for subgrid-scale physics and biogeochemical components.

To shed light on how simulated ocean circulation affects simulated ocean biogeochemistry, the Ocean Carbon-Cycle Model Intercomparison Project (OCMIP) compared simulations from different circulation models but with the same embedded diagnostic biogeochemical model (e.g., [38]).

Although the full range of Earth system models taking part in CMIP5 use different ocean biogeochemical components, we take the OCMIP approach with three of them that use a common ocean biogeochemical model, PISCES [39].

In the three selected Earth System Models, each of the ocean circulation models is based on the same code, although versions differ as to resolution and subgrid-scale physics [40–44].

Methods

The land component is the global land-vegetation model ORCHIDEE [45], which simulates interactions between land and atmosphere.

The CNRM-CM5.1 model [43] couples atmosphere, land, ocean, and sea-ice components.

Compared to the estimation of preindustrial global air-sea fluxes from forward model (e.g., [46]) or inverse model (e.g., [47]), IPSLCM4 overestimates the net ocean outgassing of about 0.8 PgC y^{-1}, while the two CMIP5 models are within the range of models estimates: 0.4 PgC y^{-1} for CNRMCM5 and 0.3 PgC y^{-1} for IPSLCM5.

For assessing modeled ocean-atmosphere net heat fluxes (i.e., sum of solar radiation, longwave radiation, sensible heat transfer by conduction and convection, and latent heat transfer by evaporation of sea surface water), we use the 1981–2005 reanalysis of Yu et al. [48], which provides a monthly climatology combining observations from surface meteorological stations and satellite data.

Results

The northward transport of AABW is underestimated in IPSLCM5 and CNRMCM5 relative to observational estimates (e.g., [49]).

All models underestimate the observed strength of the ACC (e.g., [49, 50]), although simulated transport in IPSLCM5 and CNRMCM5 is more similar to the observed transport relative to the much lower transport of IPSLCM4 (i.e., 60–70 Sv lower).

Correlation coefficients between modeled and observed surface concentrations of macronutrients are high (R ~ 0.9), except for SiO_2 in IPSLCM4 (R ~ 0.6).

Models fall within the observation uncertainties knowing that SeaWiFs underestimates CHL_a surface concentration in the Southern Ocean (e.g., [51]).

In CNRMCM5, deep NO concentrations are to high, worsening with the proximity of the Southern Ocean, indicating a problem with the ventilation of deep waters in that model.

Discussion

Although IPSLCM5 and CNRMCM5 are more skillful in simulating the dynamics of upper ocean than is IPSLCM4, all models have trouble to adequately simulate mixed layer depths, both the summer minimum and winter maximum, as well as wind stress and the dominant characteristics of the large-scale geostrophic circulation (e.g., intensity and position of the ACC).

Model-data differences reveal that simulated Alk-DIC is generally too weak in the high latitudes, particularly the Southern Ocean (<30°S).

Coarse-resolution ocean models tend to overestimate the response to surface winds (e.g., [52, 53]).

Improved ocean-sea ice coupling should lead to a better representation of the sea surface salinity in the high latitudes, a major weakness of these models, helping to improve the representation of the winter mixed-layer depths and deep-ocean ventilation, especially in the Southern Ocean.

Conclusions

Our study demonstrates that a systematic methodology based on basic skill assessment metrics (e.g., bias, root mean square error) can be valuable in understanding ocean dynamics and biogeochemistry of Earth system models.

For the next IPCC assessment, much could be learned if Earth system models would include one simple passive tracer, like CFC11, in their ocean component (e.g., run optionally for 50 years as one additional passive tracer in the online ocean component).

With this one anthropogenic tracer, it would be straightforward to assess ocean model skill in ventilating subsurface waters (e.g., [54–58]) which is crucial for ocean biogeochemistry.

Earth system models contributing to CMIP5 differ enormously, both in their physical components (atmosphere, ocean, sea-ice) and in their biogeochemical components.

Acknowledgement

A machine generated summary based on the work of Séférian, Roland; Bopp, Laurent; Gehlen, Marion; Orr, James C.; Ethé, Christian; Cadule, Patricia; Aumont, Olivier; Salas y Mélia, David; Voldoire, Aurore; Madec, Gurvan. 2012 in Climate Dynamics.

Modeling Dissolved Organic Carbon and Carbon Export in the Equatorial Pacific Ocean

https://doi.org/10.1007/s00367-014-0394-y

Abstract-Summary

In the so-called Wyrtki Box (5°S–5°N, 90–180°W), the modeled area-averaged carbon export data show the predominance of the particulate organic carbon flux.

Nearly as important is the dissolved organic carbon export flux, at 6.62 mmol C m^{-2} day^{-1}.

The modeled particulate inorganic carbon (PIC) export flux of 2.07 mmol C m^{-2} day^{-1} is much higher than the global average, indicating a key role of PIC sedimentation in the study region.

The modeled carbon-to-nitrogen export ratio for particulate organic matter (POM) is 7.8, which is consistent with the Redfield ratio.

By implication, carbon export is markedly more efficient via DOM than via POM.

This is the case also under simulated iron enrichment conditions, although there are measurable increases in carbon export efficiency for both DOM and POM.

Introduction

It has long been known that the equatorial Pacific Ocean plays a major role in the global carbon cycle mainly through the combined effects of outgassing of CO_2 to the atmosphere, and the export of organic carbon and particulate inorganic carbon (PIC) to the deep sea [59]

In the equatorial Pacific, initial estimates found that DOC is the major form of exported biogenic carbon [60, 61]; later studies challenged this, arguing that DOC export is less than half of the new carbon production [62–64].

Most of this flux occurs in the Pacific upwelling region, and therefore changes in PIC production in this region would significantly impact the global carbon cycling [65].

Most of these models focus only on biogenic particulate carbon (POC or PIC) export and its relation to CO_2 release, without considering DOC cycling.

Model performance was evaluated in reconstructing the carbon cycle of the equatorial Pacific upwelling region.

Methods

This model includes 31 state variables: three phytoplankton functional groups in three different biomass forms, i.e., picoplankton (nitrogen P1, carbon C1, chlorophyll Chl1), diatoms (nitrogen P2, carbon C2, chlorophyll Chl2), and coccolithophorids (nitrogen P3, carbon C3, chlorophyll Chl3); two size classes of zooplankton (microzooplankton and mesozooplankton in nitrogen (Z1, Z2) and carbon biomass (ZC1, ZC2) forms); detritus differentiated in terms of particulate organic nitrogen/carbon (PON, POC), particulate inorganic carbon (PIC), and biogenic silica ($bSiO_2$); silicate ($Si(OH)_4$), phosphate (PO_4), dissolved oxygen (DO), total alkalinity (TAlk), total CO_2 (DIC), nitrate (NO_3), ammonium (NH_4), bacteria nitrogen (BAC), as well as labile dissolved organic nitrogen/carbon (LDON, LDOC), colored labile dissolved organic carbon (CLDOC), semi-labile dissolved organic nitrogen/carbon (SDON, SDOC), and colored semi-labile dissolved organic carbon (CSDOC).

Cycling of carbon is included in the model using different C:N ratios for phytoplankton, zooplankton, bacteria, and detritus.

Results

Modeled surface concentration is about 0.04 mmol C m^{-3}, and increases with depth.

Modeled surface DIC concentration is 2,050.6 mmol C m^{-3}, and increases to 2,109.7 mmol C m^{-3} at the bottom of the euphotic zone (120 m depth).

Baseline values (deep water) were added to the modeled data (47.0 mmol C m^{-3} for DOC, and 3.1 mmol N m^{-3} for DON) based on observations in the deep equatorial

Pacific region (34 ± 14 mmol C m^{-3} for DOC [66, 67]; 2.6 ± 0.64 mmol N m^{-3} for DON [68]).

Modeled surface DON concentration is 4.55 mmol N m^{-3}, which is within the observed range of 5.0 ± 0.71 [68].

Modeled surface DOC concentration is 66.7 mmol C m^{-3}.

Discussion and conclusions

Of the high C:N ratio of exported DOM, the mean C:N ratio of total export organic fluxes at the bottom of the euphotic zone in the model is 9.73, which is 47% higher than the Redfield ratio (6.625), implying that using a constant Redfield ratio in the calculation would significantly underestimate the organic carbon export in this region.

DOC concentration increases from 19.7 to 24.1 mmol C m^{-3} due to phytoplankton and zooplankton biomasses increasing during the whole 30-day iron enrichment period, and starts to decrease 32 days later.

The C:N ratio of exported DOM increases from 13.8 to 14.2 over the first 9 days, and then starts to decrease but remains above that of the standard model run until 50 days later.

The C:N ratio of exported POM increases from 7.8 to peak at nearly 8.4 after about 20 days, and exceeds that of the standard model run during the whole 30 days of iron enrichment.

Acknowledgement

A machine generated summary based on the work of Liu, Na; Zeng, Lili; Li, Yizhen; Xiu, Peng. 2014 in Geo-Marine Letters.

Sources, Geochemical Speciation, and Risk Assessment of Metals in Coastal Sediments: A Case Study in the Bohai Sea, China

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Abstract-Summary

To investigate the sources and toxicity of metals in Bohai Sea sediments, concentration and geochemical speciation of metals of surface sediments were measured.

Metal distributions and principal component analysis suggested that Zn, Pb, Cd, and Ag were largely derived from anthropogenic sources, whereas the majority of the other metals studied here were found to have been derived from natural rock weathering and calcareous marine biota.

The use of the threshold effects level and effects range-low values of Cd and Cr as guidelines for the Bohai Sea are of limited use as they do not account for the bioavailability and toxicity of the elements in marine environments.

Assessment of the annual metal fluxes from riverine and atmospheric sources indicates that the largest contributions of metals to the Bohai Sea were derived from the suspended particulate load of rivers.

Extended:

Metal distributions and principal component analysis showed that Zn, Pb, Cd, and Ag were largely originated from anthropogenic activities.

Introduction

The empirical SQGs assess the ecological risk of metals in sediments by using the total concentration of the metal found in the sediments.

Many researchers have shown that the total concentration of metals may not relate to its bioavailability and toxicity in sediments [69].

The RAC is based upon the hypothesis that metal availability is associated with its geochemical speciation in sediments, which is influenced by the characteristics of the sediments.

The RAC model assesses the ecological risk of metals in sediments by using the level of metals in the exchangeable and carbonate fractions because metals in these fractions are weakly bound and readily bioavailable [70, 71].

Information of metal speciation in BS sediment is scarce.

We determined the total concentrations of seventeen metals and the geochemical speciation of nine metals in BS sediments.

Materials and methods

~0.05-g samples of dried and sieved sediment were completely digested with 1.5 mL HNO_3 and 1.5 mL HF in a Teflon® vessel at 190 °C for 48 h. The digested solutions were diluted with 2% HNO_3 to a total of 40 mL. The total concentrations of major elements (Al_2O_3, Fe_2O_3, and MnO) and trace metals (Cu, Zn, Pb, Cd, Cr, Ni, Co, and Ag) were analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES; Thermal iCAP6300) and inductively coupled plasma mass spectrometry (ICP-MS; Thermo Fisher Scientific Inc, X Series II), respectively.

The residual from F3 was digested following the methods used for the total metal concentration determination to yield F4, thus permitting the total metal concentration to be calculated from the sum of the metal concentrations in the four fractions.

The Kolmogorov–Smirnov test was performed to examine the frequency distribution of the dataset of metallic element concentrations, TOC, and the mean grain size of sediments.

Results and discussion

Of the four potentially polluting metals that were generally found at high concentrations (Pb, Zn, Cd, and Ag) in BS sediments, only Cd showed high concentrations in the sediments in and around the Fuzhou River estuary.

The results suggest that the Yellow River is the most important source of metals to the BS, accounting for approximately 65% of the total riverine Cu, Zn, and Ni, 71% of Co, 81% of Cr, and approximately 39% of Pb and Cd.

The average annual sedimentary fluxes of metals to the BS have been calculated as: Fe, 15,693 × 10^3 t/year; Mn, 346 × 10^3 t/year; Cu, 11,611 t/year; Zn, 37,378 t/year; Pb, 11,862 t/year; Cd, 112.4 t/year; Co, 6069 t/year; Cr, 31,593 t/year; Ni, 14,485 t/year; and Ag, 32.1 t/year.

Conclusions

To evaluate the ecological and environmental impacts of rapid economic and industrial development on the BS, the concentrations and geochemical speciation of metals in surface sediments were measured.

The sedimentary fluxes of the potentially polluting metals, including Zn, Ag, Pb, and Cd, were mainly deposited in zones II, III, IV(b), and VIII, whereas non-contaminating metals, including Fe, Mn, Cu, Co, Cr, and Ni, were deposited in zones II, III, IV(b), and VI zones, suggesting that the northern Liaodong Bay is a major sink for pollutants.

Of risk assessment by empirical SQGs and RAC methods, Cd presents a high risk, Cu, Pb, Ni, and Co pose a low risk, whereas Zn and Cr present no risk to the ecology of the BS.

The TEL and ERL guidelines are of limited use when estimating the ecological risks and toxicity of Cd and Cr in the BS because the total metal concentrations are not directly proportional to their toxicity in the marine environment.

Acknowledgement

A machine generated summary based on the work of Hu, Ningjing; Liu, Jihua; Huang, Peng; Yan, Shijuan; Shi, Xuefa; Ma, Deyi. 2017 in Environmental Earth Sciences.

Silicon and Zinc Biogeochemical Cycles Coupled Through the Southern Ocean

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Abstract-Summary

The striking similarity of the depth profiles of zinc to those of silicate suggests that the uptake of both elements into the opaline frustules of diatoms, and their regeneration from these frustules, should be coupled.

Since opaline frustules dissolve deep in the water column while organic material is regenerated in the shallow subsurface ocean, there is little reason to expect the observed close similarity between zinc and silicate, and the dissimilarity between zinc and phosphate.

We combine observations with simulations using a three-dimensional model of ocean circulation and biogeochemistry to show that the coupled distribution of zinc and silicate, as well as the decoupling of zinc and phosphate, can arise in the absence of mechanistic links between the uptake of zinc and silicate, and despite contrasting regeneration length scales.

Our simulations indicate that the oceanic zinc distribution is, in fact, a natural result of the interaction between ocean biogeochemistry and the physical circulation through the Southern Ocean hub.

Main

The processes that control the removal of Zn from the photic zone, its regeneration in the deep ocean, and its return to the surface via the ocean circulation, are a key part of the dynamics of oceanic nutrient chemistry [72].

Rationales for the deep maximum in Si relative to organic-associated nutrients, nitrate and phosphate, have emphasized two key processes: vertical cycling with a greater regeneration length scale of diatom opal relative to organic matter (for example, Refs. [73, 74]); and rapid depletion of Si relative to organic-associated nutrients in the surface Southern Ocean, creating distinct water mass signatures that are exported to the rest of the global ocean [75, 76].

For Zn it has been tentatively suggested that uptake of Zn and Si may be linked, and that increased Si uptake by diatoms due to Fe limitation may explain co-variation of Zn and Si observed in high-latitude nutriclines [77].

The first of these two views would suggest that the oceanic cycle of Zn is dominated by uptake into and regeneration from diatom opal.

Diatom uptake in the Southern Ocean couples Zn and Si

Beneath which the Southern Ocean water column is vigorously mixed and rather homogeneous (for example, Ref. [78]).

This export, which may be aided by the rapid blooming and equally rapid population collapse that is characteristic of diatom ecology (for example, Refs [79, 80]), results in a Zn and Si deficit relative to PO_4 in the mixed layer, which is the source of upper ocean water masses such as Antarctic Intermediate Water (AAIW) and SAMW.

Data for stations proximal to the Southern Ocean, at 40° S in the South Atlantic (entire water column, blue diamonds [81]), clearly show two different behaviours, with the deep ocean lying close to the Antarctic Zone data, and the upper ocean data reflecting the much lower slope expected for water masses sourced in the mixed layer of the Southern Ocean, from which Zn has been stripped.

The Southern Ocean hypothesis tested in an ocean model

In the biogeochemical model, PO_4 and Si cycling are treated completely independently, whilst Zn cycling is explicitly tied to that of P. Zinc in the oceanic dissolved pool is present as both inorganic Zn (Zn') and complexed with an organic ligand (ZnL).

It is currently unclear exactly why Southern Ocean diatoms exhibit high Zn/P uptake ratios, but the high values seen in data [82] emerge from the model simply from the fact that upwelled water in the Southern Ocean contains high concentrations of Zn so that not all of it is complexed by organic ligands, a finding that is also supported by data [83].

The finding that Zn distributions in the global ocean are so profoundly influenced by the stoichiometry of uptake in the Southern Ocean has relevance for studies of other trace metals, their oceanic distributions, and relationships between different nutrients.

Phytoplankton uptake stoichiometry, speciation of metals in the photic zone, and their systematics in regions of the ocean that are hubs for the physical circulation, are probably as important for other metals as they are for Zn in determining global ocean distributions.

Methods

The physical model is coupled to a biogeochemical model that simulates the internal oceanic cycling of phosphorus (as phosphate, PO_4, and dissolved organic phosphorus, DOP), zinc (Zn) and silicate (Si).

Biogeochemical model simulations were initialized with constant nutrient tracer fields (ocean-mean concentrations of 2.17 μM, 5.4 nM and 92 μM for PO_4, Zn and Si, respectively) and integrated forward for 5,000 model years.

Zinc uptake in the surface ocean is tied to PO_4 uptake via a dimensionless stoichiometric parameter $r_{Zn:P}$(see section on Zn uptake parameterization below).

This surface-ocean uptake drives an implicit export flux of particulate Zn, which remineralizes identically to the implicit particulate P flux.

In our model formulation, Si cycling is entirely biogeochemically independent of PO_4 and Zn cycling.

Acknowledgement

A machine generated summary based on the work of Vance, Derek; Little, Susan H.; de Souza, Gregory F.; Khatiwala, Samar; Lohan, Maeve C.; Middag, Rob. 2017 in Nature Geoscience.

Oceanographic and Biogeochemical Drivers Cause Divergent Trends in the Nitrogen Isoscape in a Changing Arctic Ocean

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Abstract-Summary

Nitrogen stable isotopes ($\delta^{15}N$) are used to study food web and foraging dynamics due to the step-wise enrichment of tissues with increasing trophic level, but they rely on the isoscape baseline that varies markedly in the Arctic due to the interplay between Atlantic- and Pacific-origin waters.

$\delta^{15}N$ increases in the Pacific-influenced high Arctic due to increased primary production, while Atlantic sector decreases result from the integrated effects of Atlantic inflow and anthropogenic inputs.

Introduction

In recognition of the sensitivity of Arctic ecosystems to accelerating anthropogenic influence, numerous studies have used stable isotopes as a means to construct and investigate the changing dynamics of Arctic food webs (e.g. [84–87]).

An essential requirement of stable isotope investigations is knowledge of the "isoscape", which is the baseline isotopic values of phytoplankton or detritus, at a scale relevant for the animal or food web of interest [88].

Without a clear understanding of how and why the Arctic isoscape changes in space and time, it becomes challenging to not only construct food webs at Arctic-relevant scales but also to disentangle shifts in food web structure from shifts in oceanography and biogeochemical cycling [89].

We explore how and why the Arctic isoscape of nitrogen responds to rapid changes in environmental conditions using a global ocean-biogeochemical model [90].

Methods

This global ocean-biogeochemical model resolves oceanographic exchanges between the Arctic and the major oceans, accounts for climate-driven shifts in physical properties like sea ice extent and surface temperature, and predicts the resulting changes in biogeochemical properties, like nutrient concentrations, primary production and isoscape values.

Processes of relevance for the Arctic Ocean nitrogen isoscape include changes in the contribution of Pacific and Atlantic water, phytoplankton assimilation of nitrogen (i.e. primary production), sedimentary denitrification, and external inputs of nitrogen from rivers and atmospheric deposition.

Emissions-driven simulations involved forcing our ocean-biogeochemical model with historical and future anthropogenic emissions, which emulated climate change but with trends and variability unique to the climate model.

Emissions-driven simulations involved forcing the NEMO–PISCESv2 ocean-biogeochemical model with physical conditions provided by the IPSL-CM5A-LR Earth System Model under historical conditions until 2005 ce and following the Representative Concentration Pathway 8.5 (RCP8.5) between 2005–2100 ce [91] as part of the Coupled Model Intercomparison Project phase five [92].

Results

These physical changes resulted in a multi-decadal (mean conditions in 2009–2019 minus mean conditions in 1970–1990) drawdown of surface NO_3, increases in organic matter, and an increase in the isotopic gradient between the Pacific-influenced seas of the high Arctic and the Atlantic-sector seas.

Weak declines or even slight increases in surface NO_3 occurred in the Atlantic-sector seas of the Labrador, Barents, East Greenland and Irminger Basins, possibly symptomatic of increasing NO_3 transport into the region from the North Atlantic [93] and/or increased seasonal mixing associated with the erosion of salinity stratification [94].

The contribution of riverine fluxes also had little effect, with the exception of the Southern Beaufort Sea, where the multi-decadal increase in $\delta^{15}N_{POM}$ appeared to depend on the riverine fluxes that stimulated local primary production.

This effect was absent when anthropogenic N_r deposition was not included, which showed little difference with the preindustrial control as the increase in primary production that raised $\delta^{15}N$ was compensated for by the greater Atlantic inflow that reduced $\delta^{15}N$.

Implications

$\delta^{15}N$ of bulk tissue is classically used to estimate trophic position [95], but is highly influenced by change at the $\delta^{15}N$ baseline.

Spatial and temporal variations in the nitrogen isoscape must, therefore, be considered to accurately interpret spatial and/or temporal changes in trophic position of consumers when using $\delta^{15}N$ of bulk tissue [89].

Accurate estimation of trophic position of predators is, therefore, crucial to manage and protect ecosystems, especially in the rapidly changing Arctic.

The changing nitrogen isoscape must be constrained to accurately trace changing ecological interactions in the face of borealisation and other climate-driven shifts within Arctic ecosystems.

Both sectors of the Arctic experienced increases in primary production in our simulations, as is the case in other models [96], but experienced divergent trends in the isoscape due to additional drivers in the Atlantic-sector seas.

Acknowledgement

A machine generated summary based on the work of Buchanan, Pearse James; Tagliabue, Alessandro; de la Vega, Camille; Mahaffey, Claire. 2021 in Ambio.

Two Decades of Tropical Cyclone Impacts on North Carolina's Estuarine Carbon, Nutrient and Phytoplankton Dynamics: Implications for Biogeochemical Cycling and Water Quality in a Stormier World

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Abstract-Summary

Individual storms had unique and, at times, significant hydrologic, nutrient-, and carbon (C)-loading impacts on biogeochemical cycling and phytoplankton responses in a large estuarine complex, the Pamlico Sound (PS) and Neuse River Estuary (NRE).

With regard to C cycling, NRE-PS was a sink for atmospheric CO_2 during dry, storm-free years and a significant source of CO_2 in years with at least one storm, although responses were storm-specific.

Historic flooding after Hurricanes Joaquin (2015) and Matthew (2016) provided large inputs of C from the watershed, modifying the annual C balance of NRE-PS and leading to sustained CO_2 efflux for months.

Storm type affected biogeochemical responses as C-enriched floodwaters enhanced air–water CO_2 exchange during ‘wet’ storms, while CO_2 fluxes during ‘windy’ storms were largely supported by previously-accumulated C. Nutrient loading and flushing jointly influenced spatio-temporal patterns of phytoplankton biomass and composition.

Introduction

Prior studies have documented the impact of tropical cyclones on major biogeochemical processes in estuarine and coastal systems, including air–water CO_2 exchange, nutrient loading and regeneration, and re-mineralization of soil organic carbon (C) [97–99].

Previous work documented profound impacts of tropical cyclones on lagoonal and semi-enclosed water bodies separated from oceans and seas by sandbars, barrier islands, and reefs because of restricted water exchange and relatively long water-residence times [100–102].

Effects of recent tropical cyclones on water quality, habitat, and fisheries in NRE-PS vary substantially in type, magnitude, and duration [103–110], with large storm events exerting biogeochemical impacts lasting from several months into subsequent years [105–107, 111].

We draw on extensive data from long-term monitoring programs to define relationships between nutrient and C inputs, impacts on water quality, habitat conditions, and biological responses from storm-related perturbations in comparison to more chronic, seasonal patterns.

Methods and materials

Nutrients measured at ModMon stations included: total dissolved nitrogen (TDN), nitrate plus nitrite ($NO_3^- + NO_2^-$), ammonium (NH_4^+), soluble reactive phosphate (SRP), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), particulate organic carbon (POC), and particulate nitrogen (PN).

Chlorophyll a (Chl-a) was measured for near-surface and near-bottom samples by filtering 50 mL of NRE water onto GF/F filters.

Impacts of tropical cyclones on estuarine carbon, nutrient and algal biomass related parameters were determined for each storm type for the NRE and southern PS.

For each parameter and for both the NRE and PS, volume weighted averages were calculated to provide a single metric for examining the response of each water body.

Following these estuary-wide analyses, phytoplankton biomass as Chl-a was examined with a greater degree of spatial resolution in the NRE, where averaging across the estuary may obscure significant differences in downstream Chl-a spatial gradients due to storm impacts.