Marine Variables

Introduction

In the coming decades the ocean's biogeochemical cycles and ecosystems will become increasingly stressed by at least three factors: rising temperatures, ocean acidification and ocean de-oxygenation. This will affect the oceans in ways that society is only beginning to fathom. You can explore the impacts of climate change on marine biogeochemical cycles, sea level, and sea surface temperature.

Ocean warming will not only affect organisms and biogeochemical cycles directly, but will also increase upper ocean stratification. The changes in the ocean's carbonate chemistry induced by the uptake of anthropogenic carbon dioxide (CO_2) (i.e. ocean acidification) will probably affect many organisms and processes, although in ways that are currently not well understood. Ocean deoxygenation, i.e. the loss of dissolved oxygen (O_2) from the ocean, is bound to occur in a warming and more stratified ocean, causing stress to macro-organisms that critically depend on sufficient levels of oxygen.

These three stressors—warming, acidification and deoxygenation—will tend to operate globally, although with distinct regional differences. The impacts of ocean acidification tend to be strongest in the high latitudes, whereas the low-oxygen regions of the low latitudes are most vulnerable to ocean deoxygenation. Specific regions, such as the eastern boundary upwelling systems, will be strongly affected by all three stressors, making them potential hotspots for change. Of additional concern are synergistic effects, such as ocean acidification-induced changes in the type and magnitude of the organic matter exported to the ocean's interior, which then might cause substantial changes in the oxygen concentration there. Ocean warming, acidification and deoxygenation are essentially irreversible on centennial time scales, i.e. once these changes have occurred, it will take centuries for the ocean to recover. With the emission of CO_2 being the primary driver behind all three stressors, the primary mitigation strategy is to reduce these emissions.

Nitrification is a central process in the nitrogen cycle that produces both the greenhouse gas nitrous oxide and oxidized forms of nitrogen used by phytoplankton and other microorganisms. As anthropogenic CO_2 invades the ocean, pH-driven reductions in ammonia oxidation rates could fundamentally change how nitrogen is cycled and used by organisms in the sea.

The majority of models show a decrease in primary production over much of the global ocean, with the exception of parts of the Southern Ocean and Arctic, which have an increasing trend.

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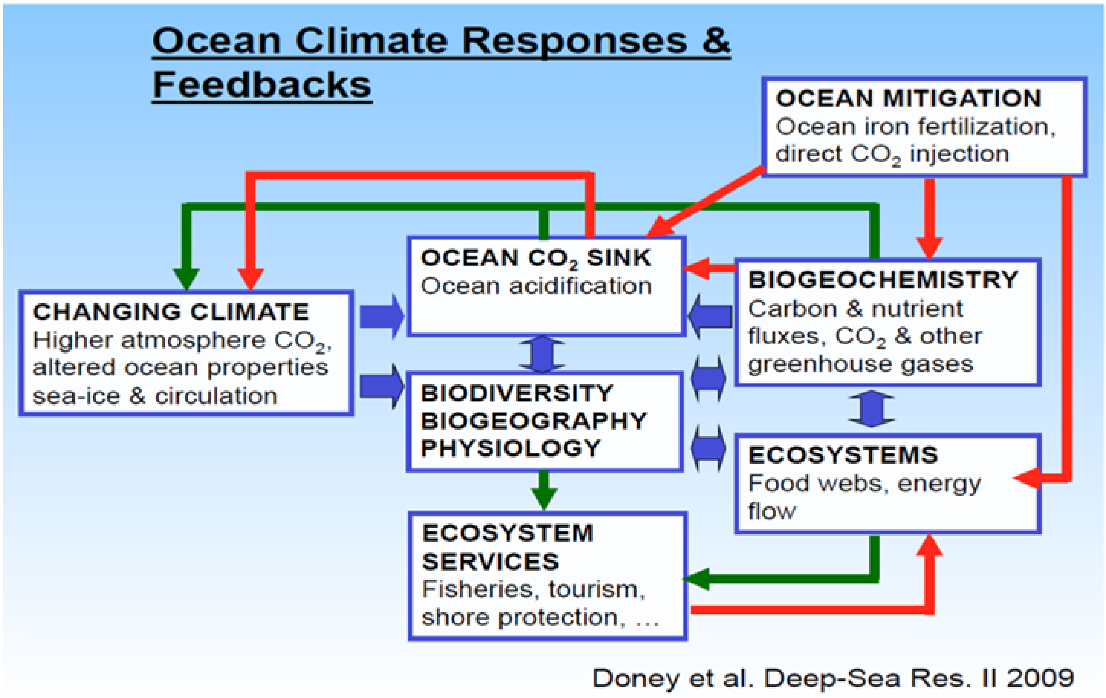
Natural resource management must also remain flexible in order to absorb the sudden and nonlinear changes that are likely to characterize the behavior of most ecosystems into the future. Overall, however, reducing greenhouse gas emissions remains the priority, not only because it will reduce the huge costs of adaptation but also because it will reduce the growing risk of pushing our planet into an unknown and highly dangerous state.



Ocean climate change responses and feedbacks

Biogeochemical models are a mathematical representation of the interactions between chemical and biological components of an ecosystem. Marine biogeochemical models are used to study the dynamics between dissolved gases (e.g. oxygen and carbon dioxide) and inorganic nutrients (e.g. phosphate and nitrate) and the lower trophic levels of the ecosystem (e.g. bacteria to plankton).

Biogeochemical models can be linked with hydrodynamic models and higher trophic level models to give a mathematical representation of the whole ecosystem (see diagram on the next page).

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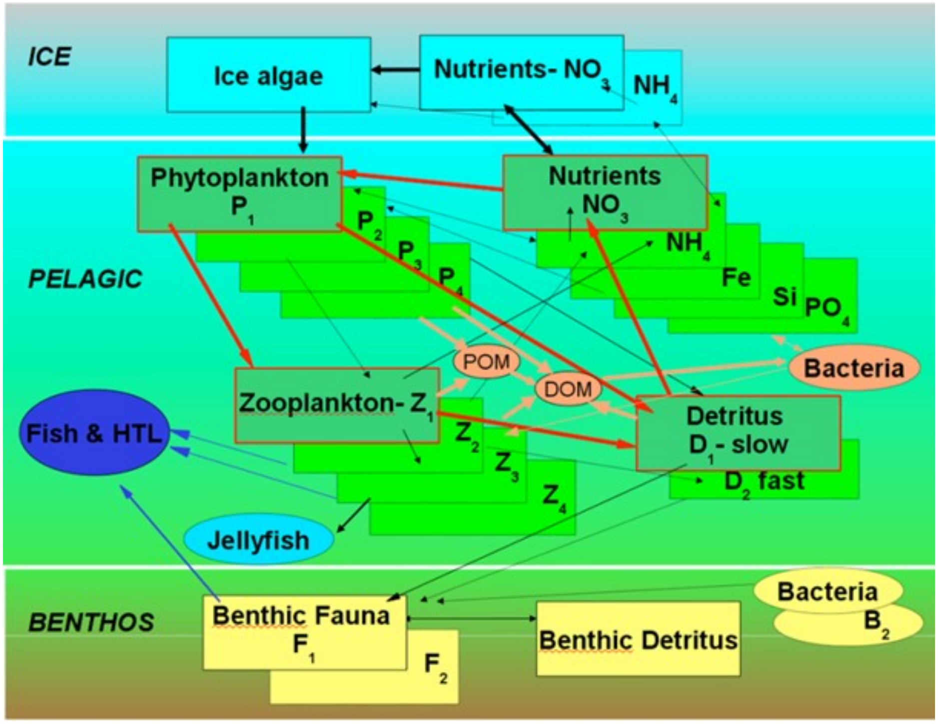

Marine Variables in Climate Insights

- ⇒ Seas surface temperature
- ⇒ Net primary productivity of carbon by phytoplankton (INTPP) (unit: gC/m3/day)
- ⇒ Dissolved Nitrate Concentration at Surface (NO3)(unit: mmol/m3)
- ⇒ Dissolved Oxygen Concentration at Surface (O2) (unit: mol/m3)
- ⇒ pH at Surface (pH) (no unit)
- ⇒ Dissolved Phosphate Concentration at Surface (PO4) (unit: mmol/m3)
- ⇒ Total Alkalinity at Surface (TALK) (unit: mol/m3)
- ⇒ Dissolved Iron Concentration at Surface (DFE) (unit: umol/m3)
- ⇒ Dissolved Silicate Concentration at Surface (SI) (unit: mmol/m3)
- ⇒ Monthly sea level rise with vertical land movement (cm) (separate document)

Marine Variables

Key Issues

Coral Reef Ecosystems

Coral reefs are highly productive and biologically diverse ecosystems that are either showing signs of deterioration or undergoing community structure changes due to a host of anthropogenic and natural factors such as bleaching, resource depletion, changing sedimentation rates and turbidity, eutrophication, cyclone damage, and natural climate variability such as El Niño Southern Oscillation. In addition to these environmental pressures, the ability of coral reefs to calcify, produce calcium carbonate ($CaCO3$) and provide framework structures as habitat may also be adversely affected by the oceanic uptake of anthropogenic $CO2$ (Sabine et al., 2004) and gradual ocean acidification.

Changes in temperature, oxygen content and other ocean biogeochemical properties directly affect the ecophysiology of marine water-breathing organisms. Previous studies suggest that the most prominent biological responses are changes in distribution, phenology and productivity. Both theory and empirical observations also support the hypothesis that warming and reduced oxygen will reduce body size of marine fishes. The assemblage-averaged maximum body weight is expected to shrink by 14–24% globally from 2000 to 2050 under a high-emission scenario. About half of this shrinkage is due to change in distribution and abundance, the remainder to changes in physiology. The tropical and intermediate latitudinal areas will be heavily impacted, with an average reduction of more than 20%.

Ocean Acidification

Acidification-driven changes in carbonate chemistry can cause diverse physiological responses among organisms. Organisms vary in their response to acidification; negative effects are evident, particularly among calcifying (shell-building) species. The process of shell formation and maintenance in marine organisms is vulnerable to acidification. Co-occurring environmental stressors can modify or exacerbate the effects of acidification.

- Biological processes influence seawater chemistry: for example photosynthesis and respiration can influence pH on a day/night basis and over longer periods.
- Biological processes contribute to carbon cycling in the ocean.
- Conditions in sediment habitats could differ from those in the overlying water column.
- Food webs and species interactions could change under conditions of ocean acidification.

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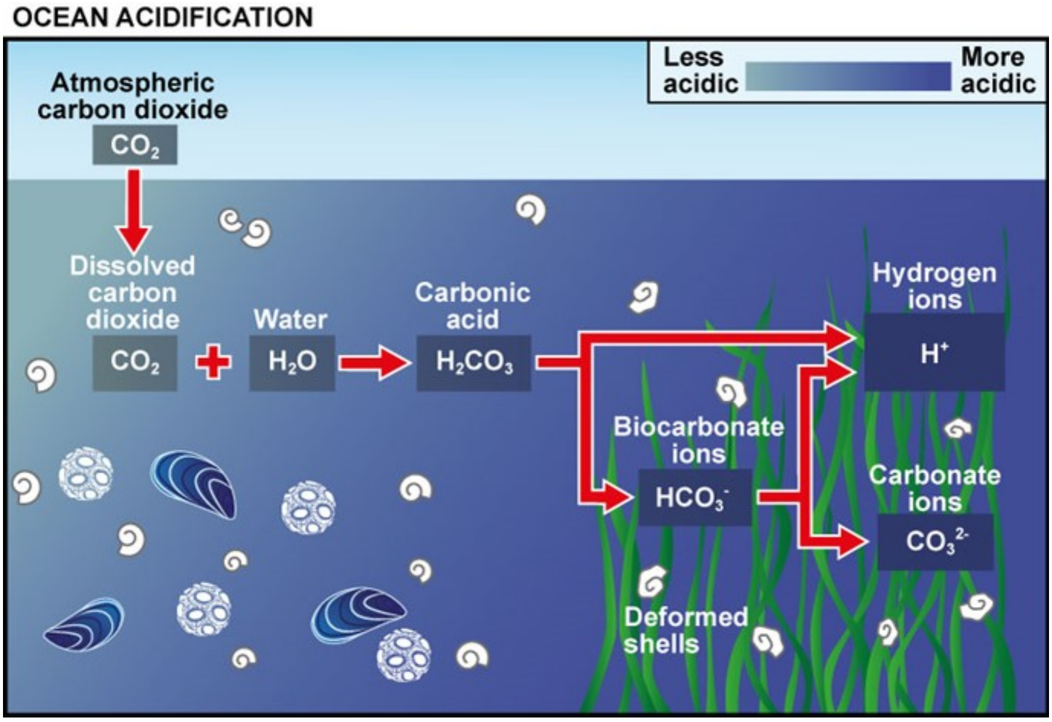
- Biological adaptation to ocean acidification conditions has been demonstrated for some species.
- The current rate of acidification is unprecedented over the past 300 million years; similar past events have been accompanied by major marine extinctions.
- Organisms in different habitats will be exposed to different conditions: upwelling systems, deep fjords, semi-isolated bays will differ in the expression of acidification.



Ocean acidification process

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GCM data availability for the marine variables (not all the GCMs have marine biogeochemical components, and not every model has all the RCP experiments), and data quality (some GCMs have missing data, and other GCMs have data quality problems). V=data

GCM name	DFE	INTPP	NO3	O2	PH	PO4	SI	SST	TALK
ACCESS1-0								v	
ACCESS1-3								v	
CANESM2		v	v		v			v	v
CCSM4								v	
CESM1-BGC	v	v	v	v	v	v	v	v	v
CESM1-CAM5								v	
CESM1-CAM5								v	
CNRM-CM5	v	v	v	v		v	v	v	v
CSIRO-MK3-6-0								v	
EC-EARTH								v	
GFDL-CM3								v	
GFDL-ESM2G	v	v	v	v	v	v	v	v	v
GFDL-ESM2M	v	v	v	v	v	v	v	v	v
GISS-E2-H								v	
GISS-E2-R								v	
HADGEM2-AO								v	
HADGEM2-CC	v	v	v	v	v		v	v	v
HADGEM2-ES	v	v	v	v	v		v	v	v
INMCM4								v	
IPSL-CM5A-LR	v	v	v	v	v	v	v	v	v
IPSL-CM5A-MR	v	v	v	v	v	v	v	v	v
IPSL-CM5B-LR	v	v	v	v	v	v	v	v	v
MIROC5								v	
MPI-ESM-LR	v	v	v	v	v	v	v	v	v
MPI-ESM-MR	v	v	v	v	v	v	v		v
MRI-CGCM3								v	
NORESM1-M								v	
NORESM1-ME	v	v	v	v	v	v	v		v

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Marine Variables

The WOA variables, processed as a baseline for Climate Insights, consist of Dissolved Nitrate Concentration at Surface, Dissolved Oxygen Concentration at Surface, Dissolved Phosphate Concentration at Surface, and Dissolved Silicate Concentration at Surface. Other variables are the ensemble mean of 1985-2005 GCM historical runs. All the baseline and change patterns were interpolated to 0.25-degree grid cells using a bi-linear interpolation method.

The unit transformation of marine biogeochemical variables follows the guide from the International Council for the Exploration of the Sea (ICES).

µmol/l = µg-at/l = mmol/m3 = µM
mg/m3 = µg/l
1 l = 1 dm3 = 10-3m3 ≈ 1 kg

Phosphorus (P)
MW P = 30.973762 µg/l P
1 µg P/l = 1/MW P = 0.032285 µmol/l

Phosphate Phosphorus (PO4-P)
MW PO4 = 94.971482 µg/l
1 µg/l PO4 = 1/ MW PO4 µg/l = 0.010529 µmol/l
1 µg/l PO4 = MW P/MW PO4 = 0.326138 µg/l P

Nitrogen (N)
MW N = 14.006720 µg/l N
1 µg N/l = 1/MW N = 0.071394 µmol/l

Nitrate Nitrogen (NO3-N)
MW NO3 = 62.005010 µg/l
1 µg/l NO3 = 1/ MW NO3 µg/l = 0.016128 µmol/l
1 µg/l NO3 = MW N/MW NO3 = 0.225897 µg/l N

Ammonium Nitrogen (NH4-N)
MW NH4 = 18.038508 µg/l
1 µg/l NH4 = 1/ MW NH4 µg/l = 0.055437 µmol/l
1 µg/l NH4 = MW N/MW NH4 = 0.776490 µg/l N

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Silicate Silicon (SiO3-Si)
MW SiO3 = 76.083820 µg/l
MW Si = 28.085530 µg/l
1 µg/l SiO3 = 1/ MW SiO3 µg/l = 0.013143 µmol/l
1 µg/l SiO3 = MW Si/MW SiO3 = 0.369139 µg/l Si
1 µg Si/l = 1/MW Si = 0.035606 µmol/l

Hydrogen Sulphide Sulphur (H2S-S)
MW H2S = 34.080894 µg/l
MW S = 32.065000 µg/l
1 µg/l H2S = 1/ MW H2S µg/l = 0.029342 µmol/l
1 µg/l H2S = MW S/MW H2S = 0.940850 µg/l S
1 µg S/l = 1/MW S = 0.031187 µmol/l

Oxygen (O2)
Molar volume at STP = 22.391 l
Molar weight of oxygen = 31.998 g
Atomic Mass of oxygen = 15.994 g/mol

1 µmol O2= .022391 ml
1 ml/l = 103/22.391 = 44.661 µmol/l
1 mg/l = 22.391 ml/31.998 = 0.700 ml/l
1 mg-at/l = 15.994x22.391/31.998 = 11.192 ml
1liter=0.001 m3
1ml/l = 44.661 mmol/m3=0.044661mol/m3

Other Variables

Current variables in Climate Insights are being developed and released regularly. Other variables such as Sea Net Primary Product (NPP) and temperature extremes, for example were recently added. It is expected that more data will be transformed and ported into Climate Insights datasets. We also wish to hear from end users of Climate Insights of other data sets that could be of interest to them or the wider risk and adaptation community for inclusion in the Climate Insights platform.