SimCLIM for ArcGIS Marine

Manual and FAQ Version 1.1

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1. Introduction

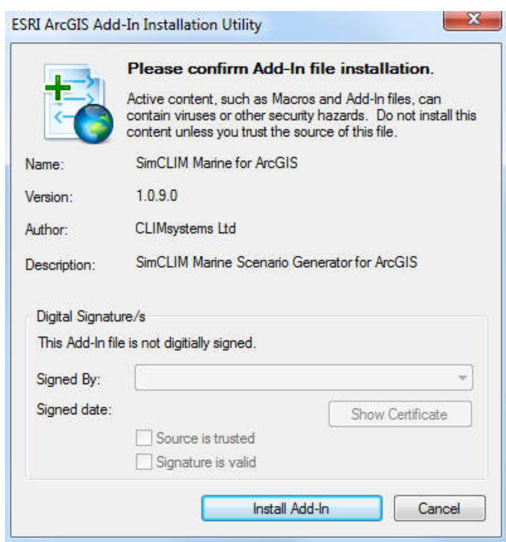
This document introduces and explains the SimCLIM for ArcGIS Marine add-in. The add-in enables ArcGIS users to produce spatial images of climate change in a very easy, quick, straight-forward process. The add-in is based on 20 years of development of the standalone SimCLIM tool, developed by CLIMsystems, and uses outputs from global climate models, produced for the IPCC (Intergovernmental Panel for Climate Change) for the 5th Assessment Reports.

This add-in incorporates the output from CMIP5 (IPCC AR5) GCM data into a simple tool in which users can select any year from 1995 up to 2100 to investigate the projections and changes in nine biogeochemical related variables for the whole global ocean area. The data generated from the SimCLIM ArcGIS Marine add-in can help marine ecosystem researchers, marine resource managers, nature conservationists, managers, planners, policy makers, and the general public by providing high resolution maps and state of the art scientific information.

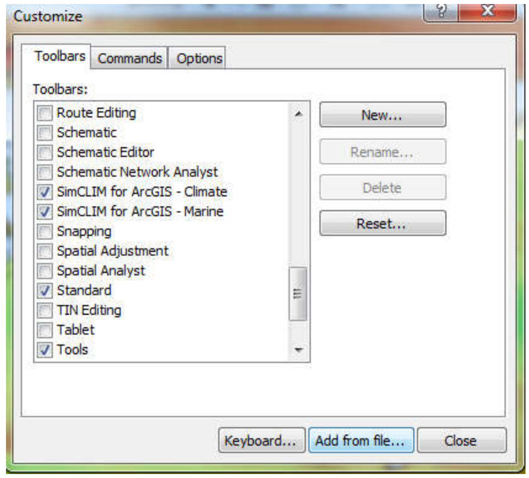
The target audience includes persons that already know how to work with ArcGIS and would like to add climate change effects to their toolbox. Some prior knowledge on climate change physics and marine biogeochemical cycles (which can be found in the IPCC AR reports) is assumed.

2. Installation

The add-in consists of a single .esriAddIn file (CLIMsystems.SimCLIM.Marine.ArcGISAddIn.esriAddin) that can be placed in any directory. If ArcGIS is installed on your computer, the .esriAddIn file will have an ArcGIS icon, and can be added to ArcGIS by double clicking it. **It is best to do this while ArcGIS is not running.**



After starting ArcGIS, if the toolbar is not already shown, it can be added to the ArcGIS toolbar through “Customize”, “Toolbars” and ticking the SimCLIM Marine toolbar.

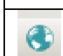
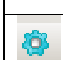


If the toolbar does not show up, you might need to change the setting for allowing Add-Ins under the Add-In Manager / Options to "Load all Add-Ins without restrictions".

SimCLIM for ArcGIS uses sets of patterns of marine biogeochemical variables and climate change for the various areas. In the basic distribution the Global area is included. The files for this area can be in any directory (maintaining the sub-directory structure), as the path can be specified through the settings option in the toolbar.

3. Usage

The SimCLIM for ArcGIS toolbar has six buttons. From right to left they offer the following functionality:

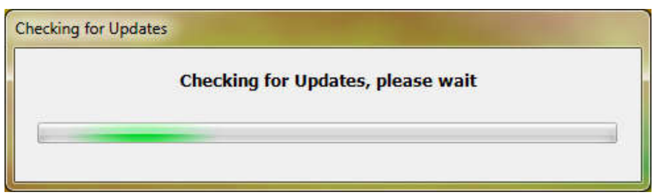
	Shows the about box, with version number of the toolbar (relevant for communicating issues with the toolbar), a link with the CLIMsystems website, as well as a link to the SimCLIM full stand-alone software web page
	Checks for updates. An internet connection needs to be available.
	Manage your product licensing.
	Here you manage the images that you create with the toolbar. A record is kept on the details of how images were created.
	Opens the options dialog-box in which defaults (data-directory, color ramps) can be set
	Opens the dialog box for defining and producing outputs for climate change scenarios (the core of the toolbar)

About

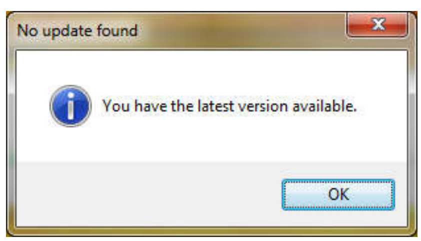
Lists the version of the toolbar and contact details and also shows your license status.

Update

This button checks if there is an update of the toolbar available. You need an internet connection for this.



If an update is found, you are prompted for the next step, otherwise (most of the time) you will get:



Licensing

The toolbar is licensed and needs a product key in order to function. The dialog is self-explanatory.

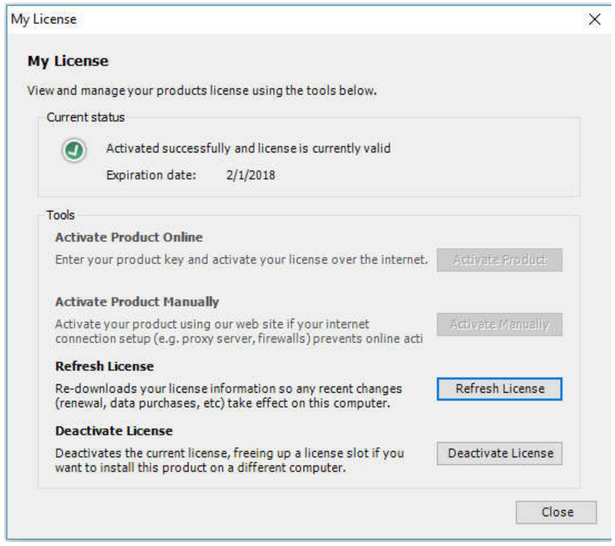
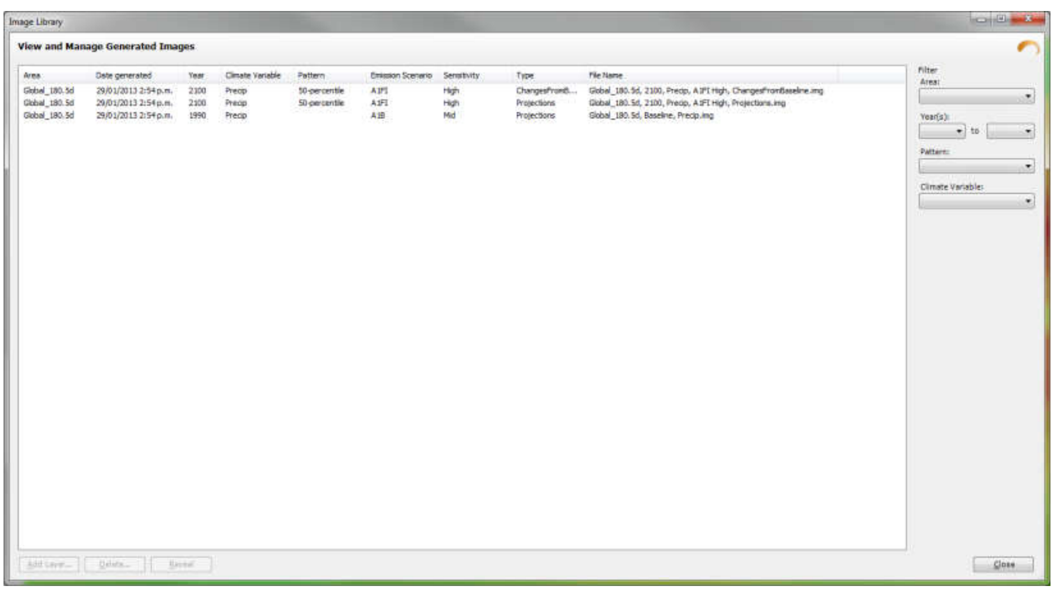


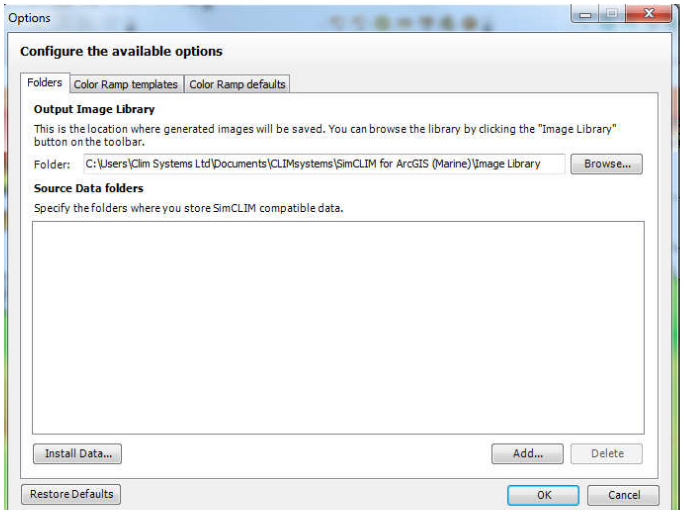
Image Library

The toolbar keeps track of the images that are created with it. The images are stored in the directory that is specified under "Settings" (see below). If maps need to be exported, this is where the original images can be found. Over time, the number of images will build up. Maintenance is left to the user. If images are no longer needed, they can be selected (using the standard Windows point-and-click, shift/ctrl functionality) and delete.



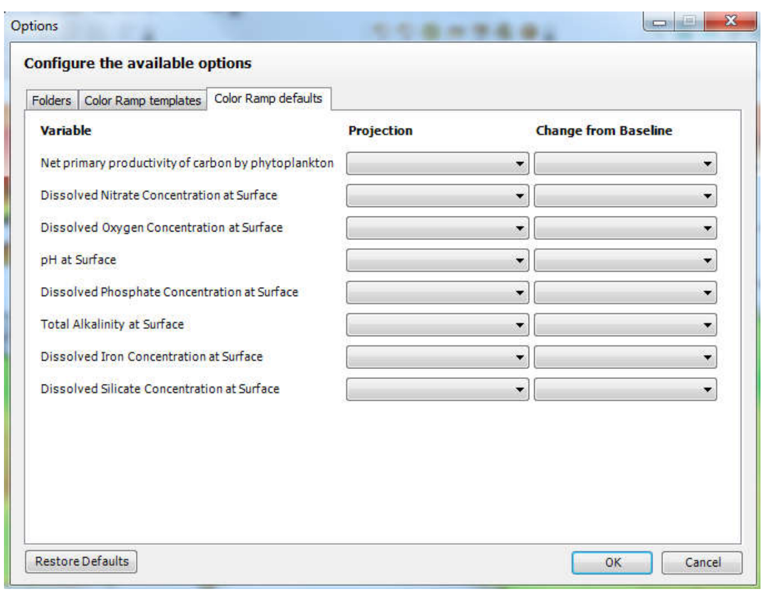
Options

The settings dialogue has three tabs: Folders, Color Ramp templates and Color Ramp defaults.



The Folders tab allows you to specify the folder where the toolbar stores created images and to list the directories in which the Climate Change data files ("patterns") are kept that will be available in the Climate Change Scenario dialog. "Install data" allows for adding new patterns that are purchased from CLIMsystems.

The Color Ramp templates allows for the defining of "low" and "high" colors for a color ramp that can be used in the mapping of outputs from Climate Change scenarios.



The Color Ramp defaults allow for setting a default color ramp for the variables that the SimCLIM for ArcGIS recognises.

Climate change scenario

The toolbar allows for generating marine change scenarios according to the AR5 results. The methodology for generating the results is the same, but the data used and some of the terminology is different.

Data source	**AR5**
baseline year	1995
baseline period	1981-2010
emission scenarios	RCPs: 2.6, 4.5, 6.0, 8.5

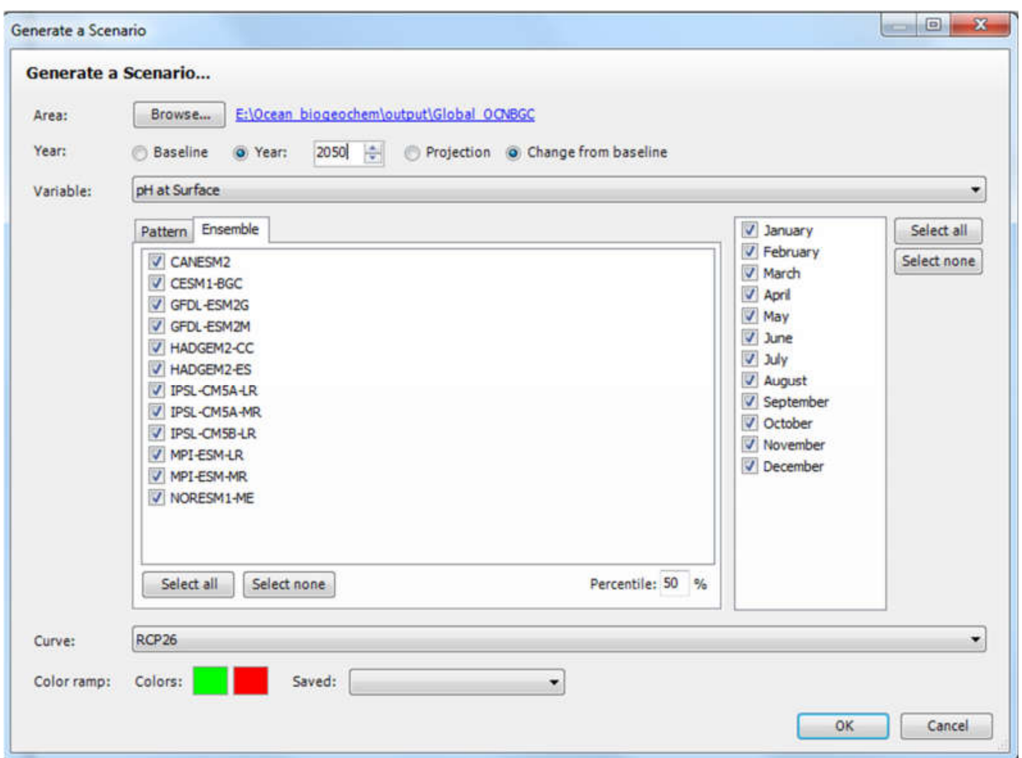
There are three types of usage of the scenario generator:

1) Generate an image for the baseline marine scenario

2) Generate a projection for a future marine scenario

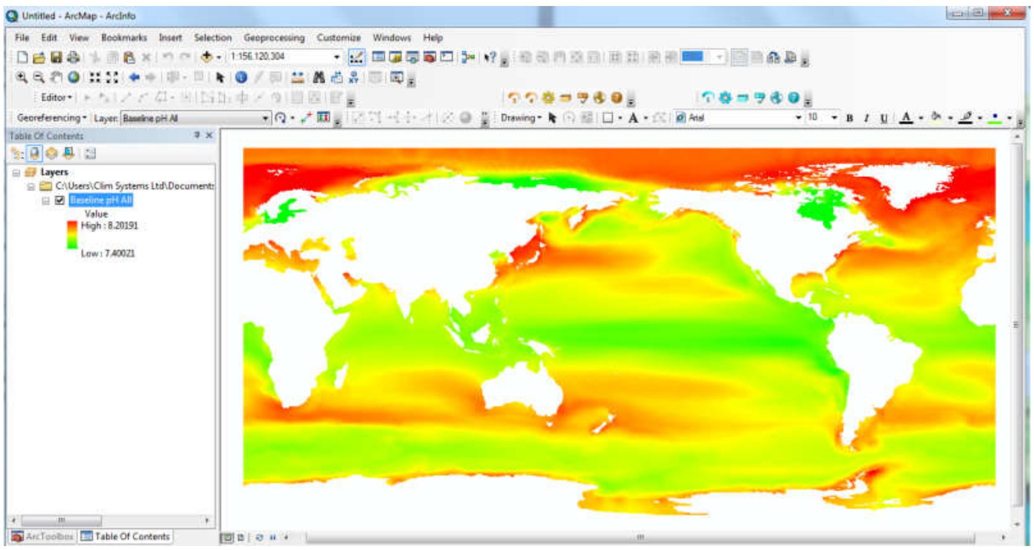
3) Generate an image with a change from baseline

These require different choices.



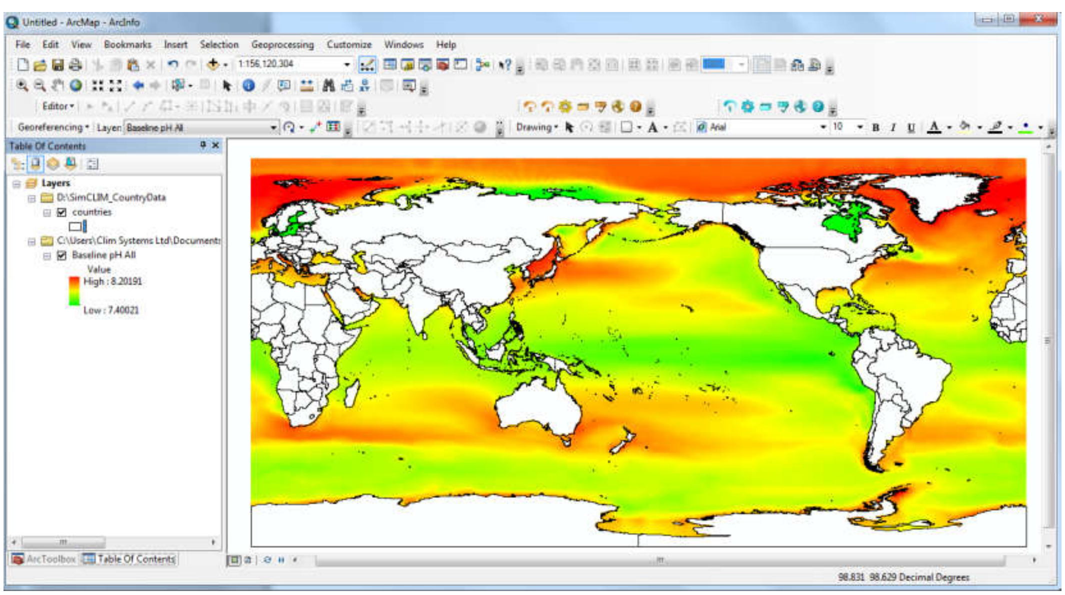
Baseline:

- Select Area (*Global*)
- Select **Baseline**
- Select months (*all*)
- Select variable (pH)
- Accept or change predefined Color Ramp, or specify From: and To: colors
- Click OK



ArcGIS functionality can be used to add features:

Country boundaries:



Then user can use the add-in data as normal ArcGIS raster data for further application.

SimCLIM for ArcGIS Marine add-in FAQ

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Q: What is the SimCLIM for ArcGIS Marine add-in

The SimCLIM for ArcGIS Marine add-in is an ArcGIS tool developed by CLIMsystems, for the purpose of exploring the impact of climate change on marine biogeochemical cycles. This add-in incorporates output from the CMIP5 (IPCC AR5) GCM data into a simple tool in which users can select any year from 1995 up to 2100 to investigate the projections and changes in nine biogeochemical related variables for the whole global ocean area. The data generated from SimCLIM for ArcGIS Marine add-in can help marine ecosystem researchers, marine resource managers, nature conservationists, managers, planners, policy makers, and general public by providing high resolution maps and state of the art scientific information.

Q: I already have SimCLIM, why do I still need SimCLIM for ArcGIS Marine?

1. The sea level rise function in SimCLIM for ArcGIS Marine is different than in SimCLIM 4.0 for Desktop.

(1) It can display sea level rise spatial map with local vertical land movement embedded, without coastal data gaps. SimCLIM 4.0 for Desktop is mainly for site specific analysis;

(2) It includes monthly variations in sea level rise which could be important for certain aresa and applications. While SimCLIM 4.0 for Desktop only has annual mean sea level rise patterns.

2. It includes Sea Surface Temperature which is a very critical variable for coastal and marine management.

3. SimCLIM for ArcGIS Marine contains a unique dataset for ocean biogeochemical variables, including, baseline and changes patterns that are indispensable for marine resource planning and management.

Q: How will climate change impact ocean biogeochemical cycles?

In the coming decades and centuries, the ocean's biogeochemical cycles and ecosystems will become increasingly stressed by at least three independent factors: rising temperatures, ocean acidification and ocean deoxygenation. Each will cause substantial change in the physical, chemical and biological environment, which will then affect the ocean's biogeochemical cycles and ecosystems in ways that society is only beginning to fathom.

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 (CO2) (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 (O2) 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 CO2 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 CO2 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.

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.

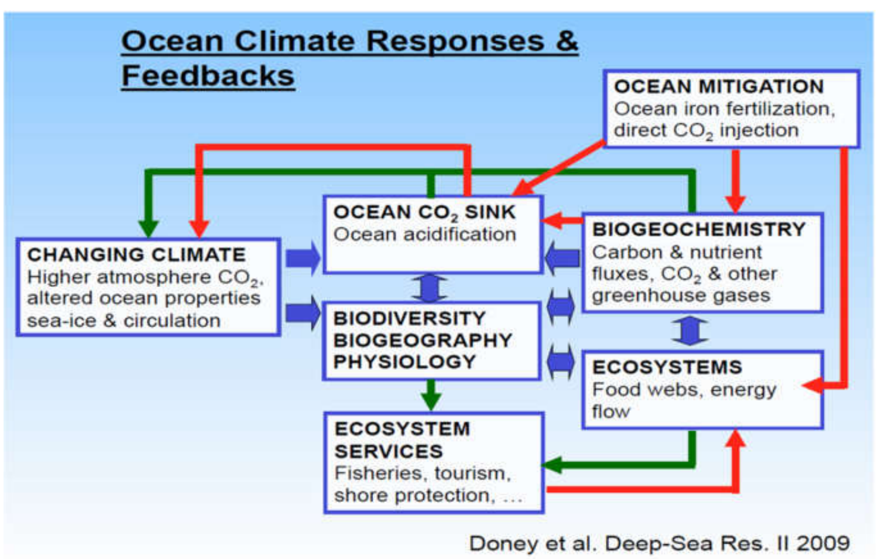


Figure1. Ocean climate change responses and feedbacks

Q: How will climate change impact the coral reef ecosystem

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.

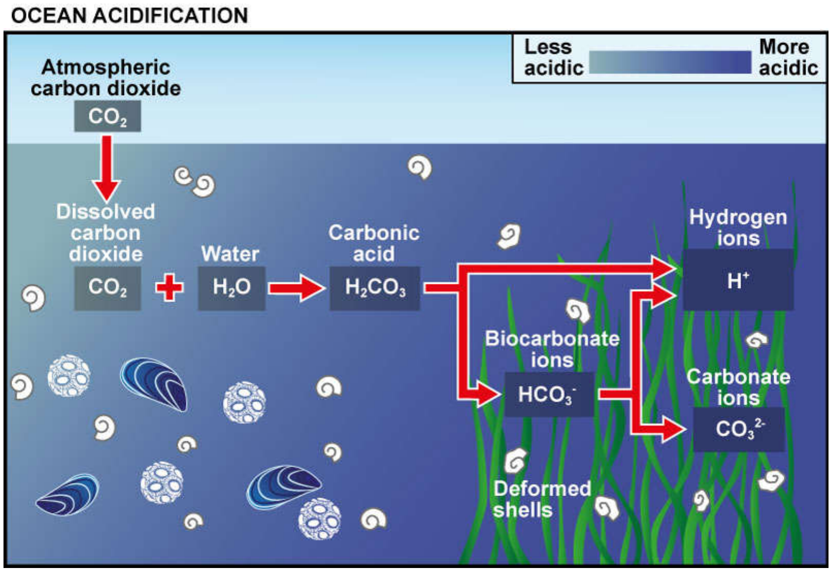
Changes in temperature, oxygen content and other ocean biogeochemical properties directly affect the ecophysiology of marine water-breathing organisms. Previous studies suggest that the most prominent biological responses are changes in distribution, phenology and productivity. Both theory and empirical 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%.

Q: What we know about responses of species and assemblages to 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.

Q: What we know about ecosystem response to ocean acidification?

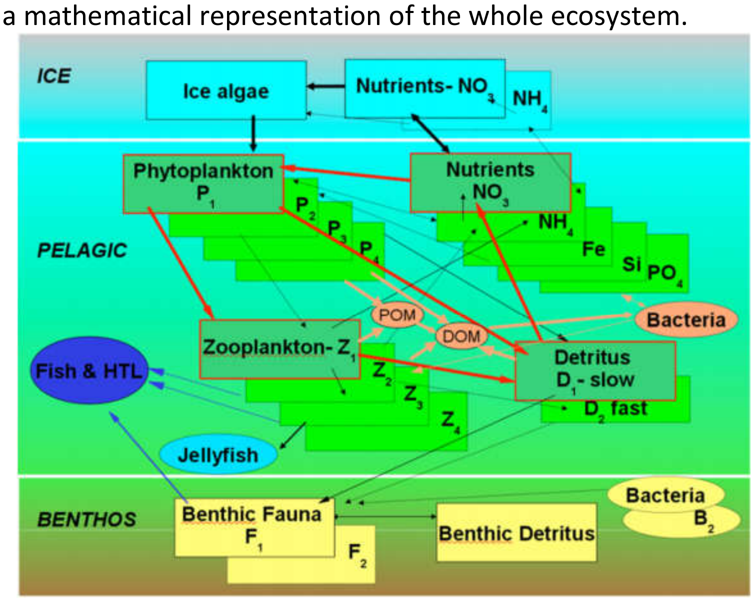
- Biological processes influence seawater chemistry: for example photosynthesis and respiration can influence pH on a day/night basis and over longer periods.
- Biological processes contribute to carbon cycling in the ocean.
- Conditions in sediment habitats could differ from those in the overlying water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



Q: What is an ocean biogeochemical model in GCMs

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.



The simplest NPZD (Nutrient, Phytoplankton, Zooplankton, Detritus) model as used in some ESMs (Earth System Models).

Q: What variables are currently available for the Marine add-in

- 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)

Q: How many and which GCMs' data were used in the Marine add-in

This number is determined by GCM data availability (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). Table 1 lists the data stored in the SimCLIM for ArcGIS Marine add-in.

Table 1 SimCLIM for ArcGIS Marine add-in GCM variable availability (all at a resolution of 0.25 degrees (approximately 27.75 kilometres)

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

Q: How can the SimCLIM for ArcGIS Marine add-in help with marine resource management?

The first step is to help decision makers, especially in developing countries, to better understand and assess the risks posed by climate change, and to better design strategies to adapt their fishing sectors to climate change. The second objective is to develop global estimates of adaptation costs in the fisheries sector of countries to inform the international community's efforts, to provide access to adequate, predictable, and sustainable support, and to provide new and additional resources to help the most vulnerable developing countries meet adaptation costs. Adaptation is here understood to mean any action taken to reduce the risk posed by the impact of climate change in a given sector of the economy, for example, fisheries. The adaptation cost is then the cost of taking such action.

Managing Risk in a Changing World

The rapid ecological shifts that are occurring in the world's oceans present major challenges for managers and policy makers. Understanding and reducing risk exposure will become increasingly important as conditions change and the likelihood of major ecological shifts increases. These changes will decrease the relevance of current models and practices for managing ecological resources and fisheries stocks, leading the management of many marine resources into "uncharted waters." Nonetheless, "no regrets" management strategies that reduce the impact of local stresses while maintaining ecological resilience will play an increasingly important role as the climate changes. Actions that reduce the flow of nutrients and sediments from coastal catchments, for example, as well as those that reduce activities such as the deforestation of mangroves and the overfishing of key ecological species (e.g., herbivores), will become increasingly important as the impacts of climate change mount.

Q: Who can get help from the SimCLIM for ArcGIS Marine add-in

- Marine ecosystem researchers
- Marine resource managers
- Nature conservationists, managers, planners and policy makers
- General public

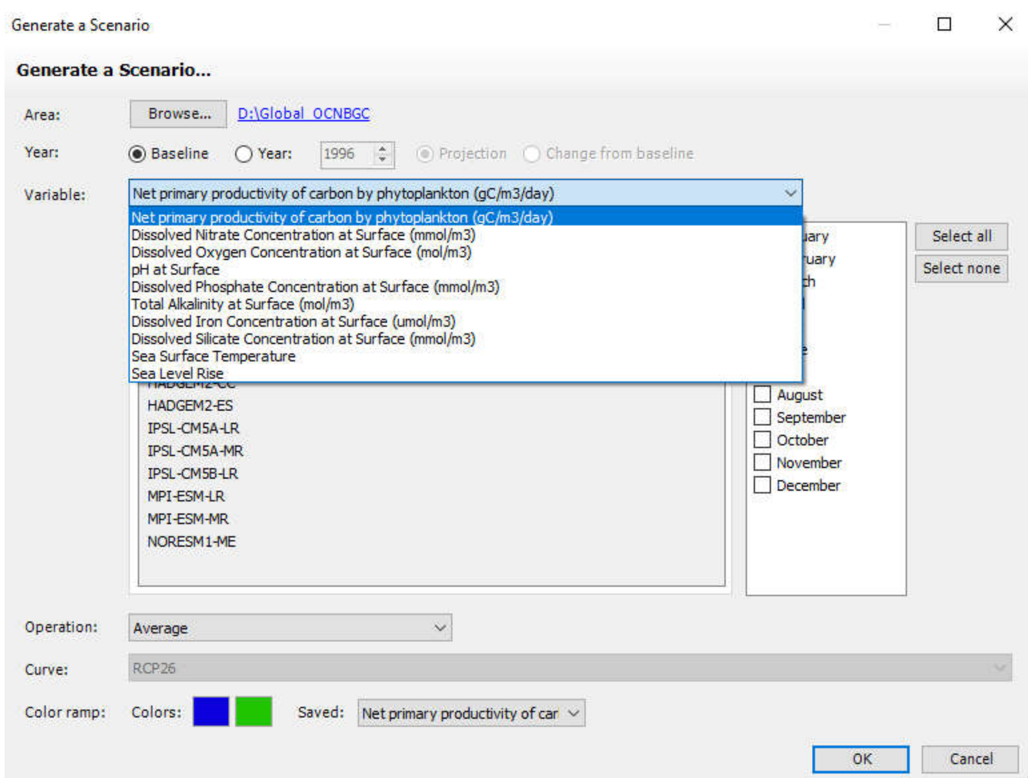
Q: How can the SimCLIM for ArcGIS Marine add-in be applied in ArcGIS?

(1) Install the SimCLIM for ArcGIS Marine add-in, and the add-in toolbar will appear in your ArcMap 10.0 or 10.1 (10.2 version pending).

(2) Select a variable, year, month, and GCMs you would like to explore along with the projections or changes.

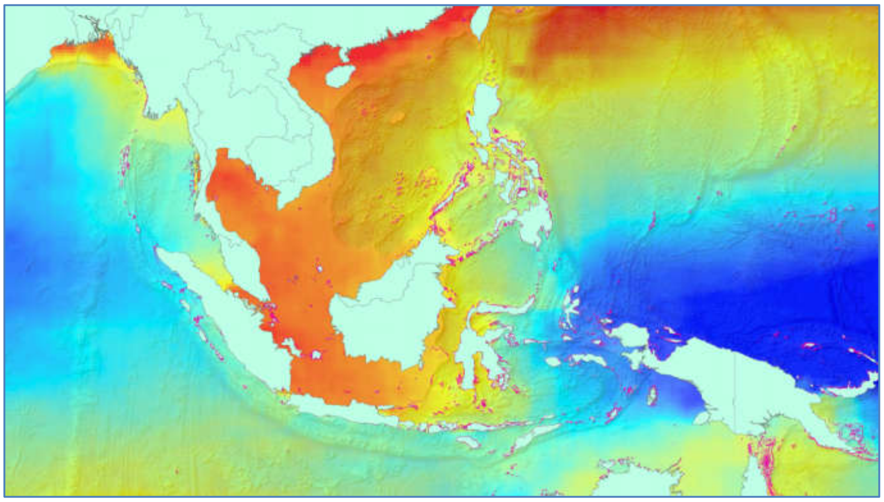
All variables are at the global scale in the current version. Customised and higher resolution study areas can be custom generated by CLIMsystems for specific end user needs. Contact info@climsystems.com or call +64 7 834 2999 to discuss customised and higher resolution study areas. Additional marine variables (such as deeper ocean thermoclines) can also be developed through consultation.

Future year: 1996-2100
Different scenarios: RCP26, RCP45, RCP60, RCP85



Q: Sample figures produced using the SimCLIM for ArcGIS Marine add-in

Ocean pH



About a third of the CO_2 released in the atmosphere dissolves in the oceans, where it slightly lowers the pH. This effect is known as ocean acidification.

Ocean acidification is of great concern: small changes in pH impact the $CaCO_3$-CO_2 equilibrium thus slowing coral growth and weakening the coral that does grow under such conditions.

The image shows the result from 12 models from the CMIP5 data for changes in pH. Because pH is a log-scale unit, the ratio of pH for 1995 and 2035 is presented.

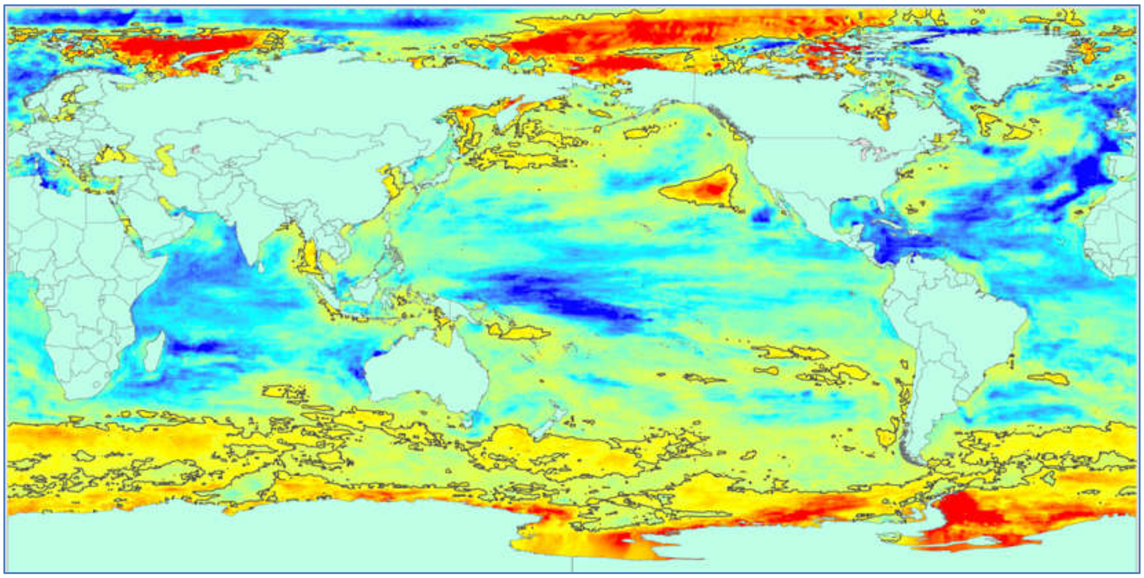
The redder colour shows a stronger change. This is mostly occurring in shallower areas, as there is an effect from temperature as well.

As the model-data (using grid-cells of 0.25°x0.25°) does not cover partial cells close to the coastline, the FILTER function of ArcGIS was used to fill in the gaps.

The pH-information is combined with other data:
- country data (grey land and black boarders)
- coral reef locations (purple)
- ocean bathymetry (from ETOPO1, through ArcGIS-online) (this layer is visible because the pH layer has been made 25% transparent)

The image is a beautiful example of how a toolbar (the CLIMsystems SimCLIM for ArcGIS Marine toolbar, in addition to the “Climate” toolbar), combines perfectly with the functionality of ArcGIS.

Net Primary Production



Changes in the surface chemistry and temperature of the oceans because of climate change, impact the primary production from phytoplankton. The image shows the distribution of the relative change in net primary production. In the blue areas production decreases, and in the yellow/red areas it increases (more than a factor of 2, by 2100 under the RCP8.5 emission pathway).

The contour lines separate the areas of increase from those decreasing.

The increase is mostly situated in the colder regions, while the decrease is primarily in the areas that are already warmer i.e. the Gulf Stream from the Gulf of Mexico to Europe is clearly visible.

Q: How was the data in the SimCLIM for ArcGIS Marine Add-in processed?

Data sources

The GCM data in the SimCLIM for ArcGIS Marine add-in from CIMP5 which is also the data source for the IPCC AR5 climate change projections. For more information of CMIP5 please visit: http://cmip-pcmdi.llnl.gov/cmip5/ guide_to_cmip5.html.

Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its Fifth Assessment Report (AR5).The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6.0, and 8.5 W/m2, respectively).

Table 2 Overview of representative concentration pathways (RCPs) (Vuuren et al. 2011)

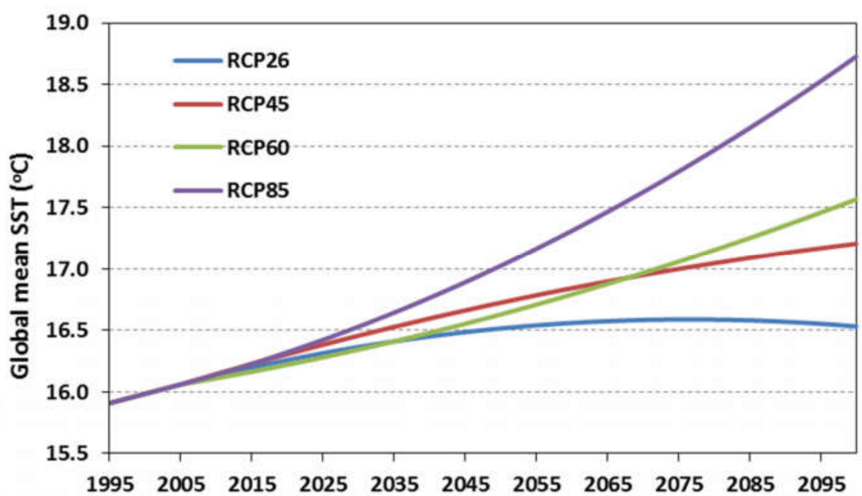
	Description[a]	Publication—IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq) by 2100.	(Riahi et al. 2007)—MESSAGE
RCP6	Stabilization without overshoot pathway to 6 W/m^2 (~850 ppm CO_2 eq) at stabilization after 2100	(Fujino et al. 2006; Hijioka et al. 2008)—AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq) at stabilization after 2100	(Clarke et al. 2007; Smith and Wigley 2006; Wise et al. 2009)—GCAM
RCP2.6	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_2 eq) before 2100 and then decline (the selected pathway declines to 2.6 W/m^2 by 2100).	(Van Vuuren et al., 2007a; van Vuuren et al. 2006)—IMAGE

[a] Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2 relative to pre-industrial levels. Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents

Pattern scaling approach

The ocean biogeochemical variables change patterns were processed using the monthly output of GCMs.

(1) Global area weighted means of each year from 2006 to 2100 were calculated for all the available GCM's RCP runs.
(2) The GCM ensemble means of each RCP were calculated.
(3) The 95 year values were fitted to smooth curved polynomial lines, that is the global annual mean change value (GV). The difference between 1995 and a projection year is called ΔGV



Global curves for sea surface temperature.

(4) For a given climate variable *V*, its anomaly ΔV^* for a particular grid cell (*i*), month (*j*) and year or period (*y*) under an RCP45:

$$\Delta V^*_{yij} = \Delta GV_y \cdot \Delta V'_{ij} \qquad (1)$$

where ΔGV being the annual global mean change of variable *V*.

(5) The local change pattern value ($\Delta V'_{ij}$) was calculated from the GCM simulation anomaly (ΔV_{yij}) using linear least squares regression, that is, the slope of the fitted linear line.

$$\Delta V'_{ij} = \frac{\sum_{y=1}^{m} \Delta GV_y \cdot \Delta V_{yij}}{\sum_{y=1}^{m} (\Delta GV_y)^2}$$

where *m* is the number of future sample periods used, 5 year average as a period, 19 period from 2006 to 2100.

The global curves and local change patterns were stored in the SimCLIM for ArcGIS Marine add-in. When user selects a variable and a projection year, equation (1) is applied to calculate the changes between the baseline period and the projection year. The projection in the SimCLIM for ArcGIS Marine add-in is the baseline plus the changes.

Baseline data sources:

World Ocean Atlas (WOA):
The description of the data please refers to http://www.nodc.noaa.gov/OC5/WOA09/pubwoa09.html.

The WOA variables were processed as the SimCLIM for ArcGIS Marine add-in baseline:
Dissolved Nitrate Concentration at Surface, Dissolved Oxygen Concentration at Surface, Dissolved Phosphate Concentration at Surface, and Dissolved Silicate Concentration at Surface.

Hadley Centre Sea Ice and Sea Surface Temperature data set
(http://www.metoffice.gov.uk/hadobs/hadisst/)

The mean of 1981-2010 data were used as the baseline for sea surface temperature baseline.

Other variables in the SimCLIM for ArcGIS Marine add-in, are the ensemble mean of 1985-2005 GCM historical runs.

All the baseline and change patterns were interpolated to 0.25 degree grid cells (roughly 27.75 kilometres around the equator) using a bi-linear interpolation method.

Q: How to convert the units of the marine biogeochemical variables

Please refer to International Council for the Exploration of the Sea (ICES)

(http://www.ices.dk/marine-data/tools/Pages/Unit-conversions.aspx)
µmol/l = µg-at/l = mmol/m_3= µM
mg/m_3= µg/l
1 l = 1 dm^3= $10^{-3}m^3$≈ 1 kg

Phosphorus (P)
MW P = 30.973762 µg/l P

1 µg P/l = 1/MW P = 0.032285 µmol/l

Phosphate Phosphorus (PO_4-P)
MW PO_4= 94.971482 µg/l
1 µg/l PO_4= 1/ MW PO_4µg/l = 0.010529 µmol/l
1 µg/l PO_4= MW P/MW PO_4= 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 (NO_3-N)
MW NO_3= 62.005010 µg/l
1 µg/l NO_3= 1/ MW NO_3µg/l = 0.016128 µmol/l
1 µg/l NO_3= MW N/MW NO_3= 0.225897 µg/l N
Nitrite Nitrogen (NO_2-N)
MW NO_2= 46.005580 µg/l
1 µg/l NO_2= 1/ MW NO_2µg/l = 0.021736 µmol/l
1 µg/l NO_2= MW N/MW NO_2= 0.304457 µg/l N
Ammonium Nitrogen (NH_4-N)
MW NH_4= 18.038508 µg/l
1 µg/l NH_4= 1/ MW NH_4µg/l = 0.055437 µmol/l
1 µg/l NH_4= MW N/MW NH_4= 0.776490 µg/l N

Silicate Silicon (SiO_3-Si)
MW SiO_3= 76.083820 µg/l
MW Si = 28.085530 µg/l
1 µg/l SiO_3= 1/ MW SiO_3µg/l = 0.013143 µmol/l
1 µg/l SiO_3= MW Si/MW SiO_3= 0.369139 µg/l Si
1 µg Si/l = 1/MW Si = 0.035606 µmol/l

Hydrogen Sulphide Sulphur (H_2S-S)
MW H_2S = 34.080894 µg/l
MW S = 32.065000 µg/l

1 μg/l H_2S = 1/ MW H_2S μg/l = 0.029342 μmol/l
1 μg/l H_2S = MW S/MW H_2S = 0.940850 μg/l S
1 μg S/l = 1/MW S = 0.031187 μmol/l

Oxygen (O_2)
Molar volume at STP = 22.391 l
Molar weight of oxygen = 31.998 g
Atomic Mass of oxygen = 15.994 g/mol

1 μmol O_2= .022391 ml
1 ml/l = 10^3/22.391 = 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

Technical Note on Monthly Sea Level Rise Change Patterns Based on the CMIP5 Data

Data and Method

The monthly changes in SLR of 28 GCMs between 1986-2005 and 2081-2100 under the RCP4.5 scenario were calculated by the pattern scaling method.

GCM data were retrieved from the Earth System Grid (ESG) data portal for CMIP5, including: the sea surface height ('zos'), the global average thermosteric sea level change ('zostoga') and the global average sea level change ('zosga') under RCP4.5 scenario. For some GCMs, only 'zosga' was available and used instead of zostoga. The data availability was shown in Table 1. Please find details on GCMs and RCP scenarios in our 2013 Data Manual, and more information on variables in http://www.climatechange2013.org/images/report/WG1AR5_Ch13SM_FINAL.pdf and http://www-pcmdi.llnl.gov/ipcc/standard_output.pdf.

The change in sea surface height was scaled by the change in global average thermal expansion by month following the pattern scaling theory (please see details in our 2013 Data Manual). The sea surface height from GCMs includes the regional variability of dynamic topography changes due to water mass advection, thermohaline circulation and to the wind-driven circulation, and did not include the tidal effects. The changes in global average thermal expansion were calculated by the changes in zostoga if it is available, or by the changes in zosga.

The value X (m/m) in patterns is interpreted as "regional sea level may rise X m when the global average sea level rises 1 m".

Table 1 The availability of SLR patterns for CMIP5.

No.	GCM	zos	zostoga	zosga
1	ACCESS1-0	√		√
2	ACCESS1-3	√		√
3	bcc-csm1-1	√		√
4	bcc-csm1-1-m	√		√
5	CanESM2	√		√
6	CCSM4	√	√	√
7	CMCC-CM	√		√
8	CMCC-CMS	√		√
9	CNRM-CM5	√	√	√
10	CSIRO-Mk3-6-0	√	√	
11	GFDL-CM3	√	√	√
12	GFDL-ESM2G	√	√	√
13	GFDL-ESM2M	√	√	√
14	GISS-E2-R	√	√	√
15	GISS-E2-R-CC	√		√
16	HadGEM2-CC	√	√	
17	HadGEM2-ES	√	√	
18	inmcm4	√	√	
19	IPSL-CM5A-LR	√	√	√
20	IPSL-CM5A-MR	√		√
21	MIROC5	√		√
22	MIROC-ESM	√		√
23	MIROC-ESM-CHEM	√	√	√
24	MPI-ESM-LR	√	√	√
25	MPI-ESM-MR	√	√	√
26	MRI-CGCM3	√	√	√
27	NorESM1-M	√	√	√
28	NorESM1-ME	√		√

Results

The ensembles of annual mean and standard deviation (SD) of SLR change were shown in Fig. 1 and Fig.2.

In general, the regional sea level may rise significant higher in north polar area (rising more than 2.2 m when the global average sea level rises 1 m) than in the other places. The most notable rise in coastal area might happen along the northeast coast of North America, likely to rise 1.9 m per 1 m rise in global average sea level. Another area to be affected by SLR is the coastal area of Norway and the North Sea.

The ensemble of annual SD of SLR patterns revealed that the seasonal variability of SLR change would be relatively small (about 0.02~0.04 m) in most places, except the coast of Alaska and Arctic.

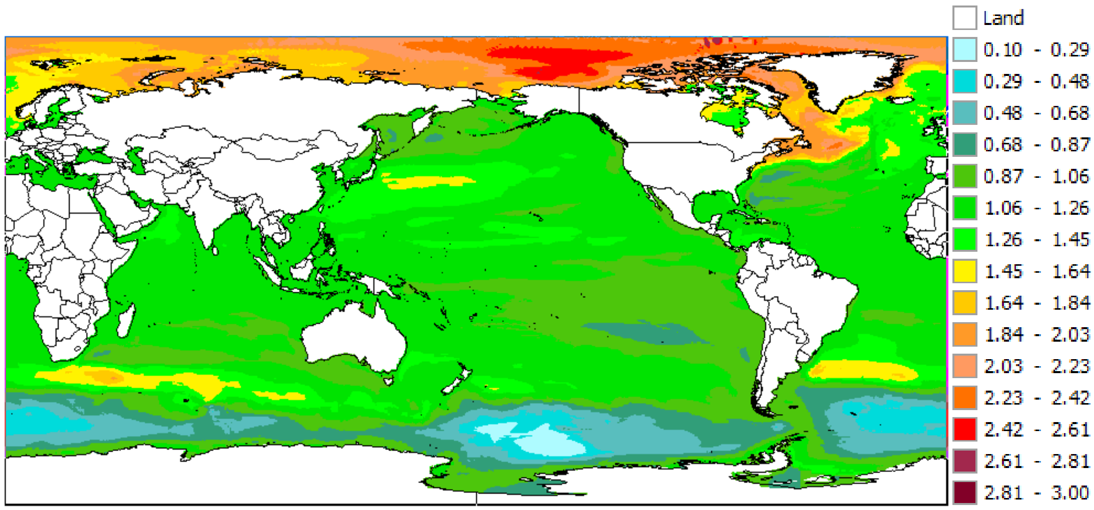


Fig. 1 The ensemble (28 GCMs) of the annual mean of 12 month SLR changes.

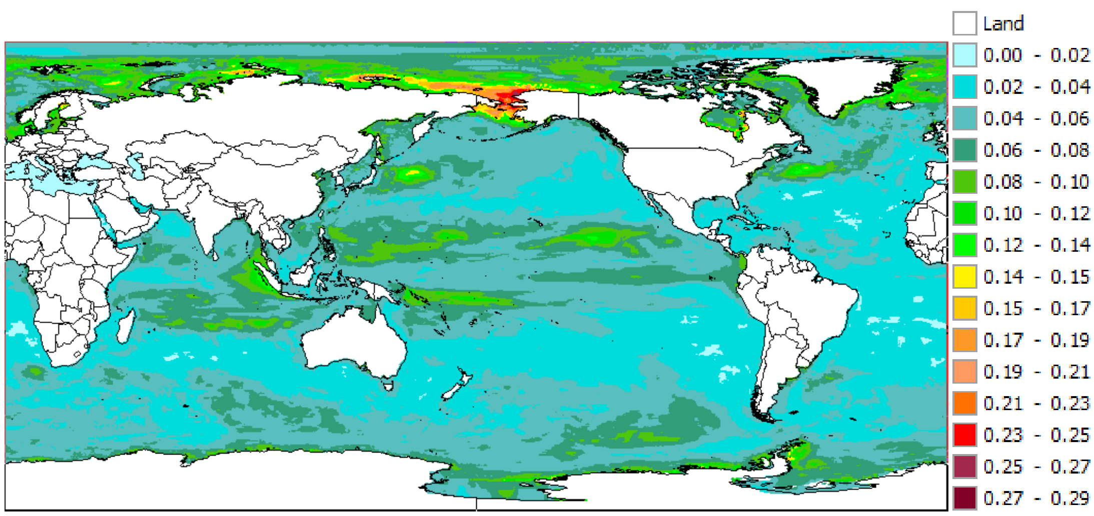


Fig. 2 The ensemble (28 GCMs) of the annual Standard Deviation (SD) of 12 month SLR changes.

To reveal the seasonal variability of SLR change, the annual highest SLR change and the annual mean SLR change were compared. Their difference (see Fig. 3) indicated the global average of the largest SLR change might be 0.04~0.08 m/m higher than the mean. The largest differences in a year are probably to appear in the Artic area (rise up to 0.91 m/m in some places). The Hudson Bay in Canada, the area around Greenland and the Baltic Sea might also suffer large seasonal variability of SLR change.

The percentage deviation of the annual highest from the annual mean (see Fig. 4) suggested quite similar results. Globally, the highest SLR change may be 5~8% higher than the mean change. The large deviations in the Arctic area, Hudson Bay, the area around Greenland, Alaska, Baltic Sea and Antarctica were probably caused by the seasonal melting of ice. The large values in middle and low latitudes had similar patterns to the surface zonal winds and ocean currents, and most of them appeared in western coasts. The seasonal variability of SLR changes might have relation with the seasonal shift of the zonal winds and current circulation.

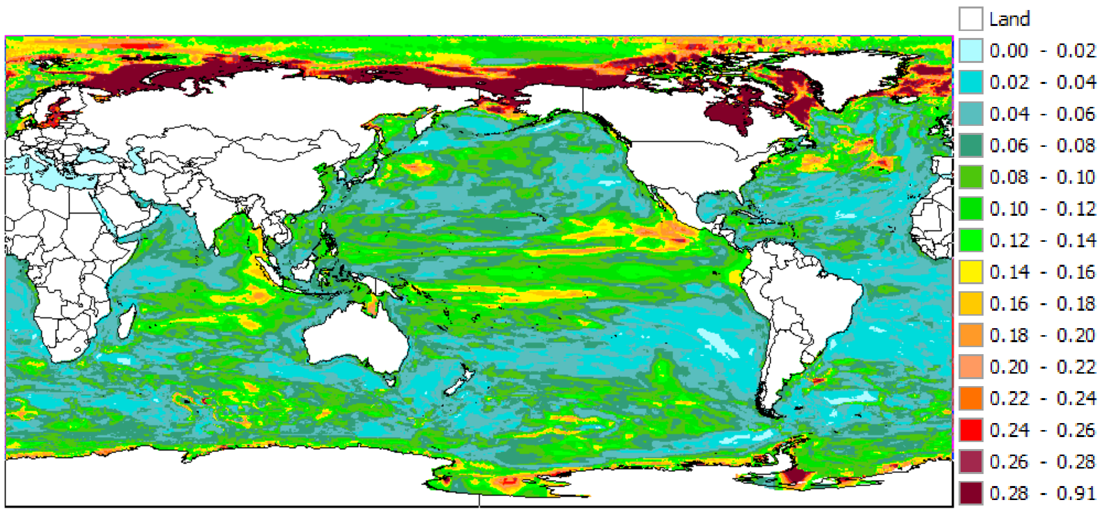


Fig. 3 Difference between the ensemble (28 GCMs) of the annual highest change of SLR and the ensemble (28GCMs) of the annual mean change of SLR.

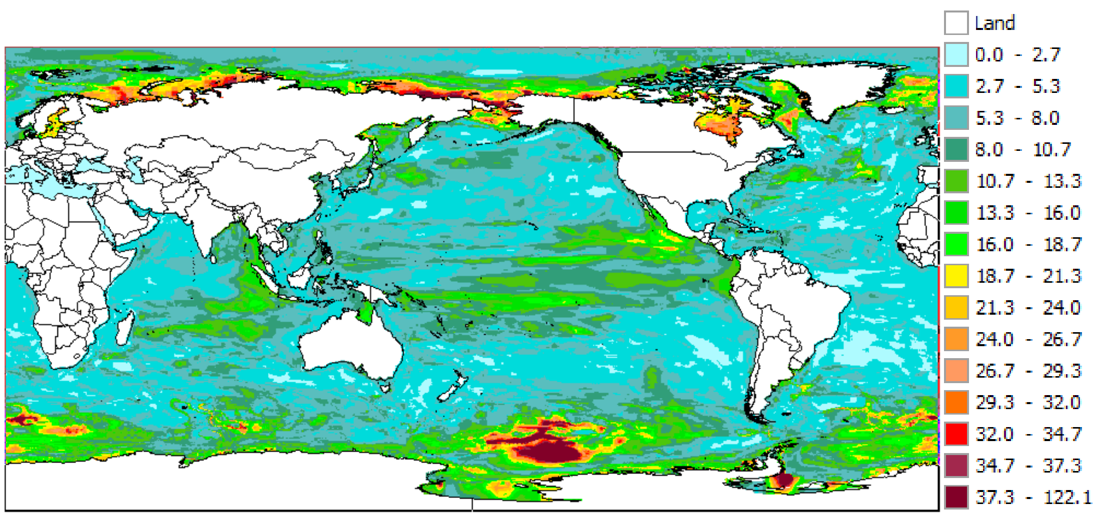


Fig. 4 Percentage deviation of the ensemble (28 GCMs) of the annual highest change of SLR from the ensemble (28 GCMs) of the annual mean change of SLR. The unit is %.

SLR monthly anomaly baseline is derived from the Satellite observations

http://www.cmar.csiro.au/sealevel/sl_data_cmar.html

Combined TOPEX/Poseidon, Jason-1 and Jason-2/OSTM sea level fields - several versions

These data sets are a combination of data from TOPEX/Poseidon, Jason-1 and Jason-2/OSTM

See Historical sea level changes - last two decades for information about recent changes to our processing

- near-global (65°S to 65°N), on a 1° × 1° grid
- monthly averages, currently from January 1993 to July 2014 (this is extended as data becomes available)
- Versions available:
  - with or without the inverse barometer correction
  - with or without the seasonal (annual + semi-annual) signal removed
  - with or without the GIA correction
- All are available as gzip'ed netCDF files, and are each about 8-9 Megabytes in size
- They all include a time series of Global Mean Sea Level (GMSL)

File name	Click to download	Inverse barometer correction	Seasonal signal	GIA correction
jb_iby_srn_gtn_giy.nc.gz	Download	Done	Not removed	Done

Use the period 1993-2012

Note: This observations don't cover polar areas (>65N and >65S), so we extended the anomaly in polar areas with the GCM ensemble.

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