PICES-2012: Summary of Scientific Sessions and Workshops

POC/TCODE Topic Session (S14)
Changing ocean biogeochemistry and its ecosystem impacts

Co-Convenors: *Tony Koslow (TCODE, USA), Steven Bograd (POC, USA), Silvana Birchenough (ICES/UK), Masao Ishii (PICES/Japan)*

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Background
Ocean biogeochemistry is undergoing rapid and growing anthropogenic change. A significant fraction of anthropogenic CO2 is taken up by the ocean, which drives down pH and reduces the saturation state of carbonate minerals like calcite and aragonite, a process known as "ocean acidification". Global climate models also predict that dissolved oxygen concentrations in the deep ocean will decline by 20-40% over the coming century or so as global warming enhances stratification of the upper mixed layer and reduces ventilation of the deep ocean. Declining oxygen levels have now been reported from mid-ocean depths in the tropical oceans and across the North Pacific. Both processes are of particular concern in the North Pacific, where the water is naturally "old" and has shallow carbonate saturation horizons, relatively low buffering capacity, and extensive oxygen minimum zones. It is anticipated that these anthropogenic influences on the global ocean will increase in coming decades as atmospheric CO2 levels and global temperatures continue to rise. We invited papers on the changing biogeochemistry of the global ocean, its impacts on organisms and ecosystem function, and emergent impacts on biogochemical cycles related to the interaction of ocean acidification and declining oxygen with climate change and other anthropogenic impacts.

Summary of Presentations
Session S14 was held on Tuesday, October 16, 2012 (full day) and was launched with an invited talk by Akihiko Murata (JAMSTEC, Japan) and included five invited presentations: Brad Seibel (URI, USA) and Curtis Deutsch (UCLA, USA). In addition, there were 15 contributed oral presentations and five posters.

The lead invited address was given by Akihiko Murata:(JAMSTEC, Japan) who reviewed decadal changes in dissolved inorganic carbon (DIC), reflecting uptake of anthropogenic CO_2 across the North and South Pacific based on repeat hydrographic sections. The pattern was surprisingly variable, with low inventory in the Equatorial Pacific and high in the subtropical gyres. In deeper waters, high CO_2 found in mode waters but deeper, only in Antarctic Intermediate Water, not so much in North Pacific Intermediate Water. Overall ~40% of the oceanic uptake of CO_2 is found in the Pacific Ocean from 50S – 65N. Dist processes have not changed significantly over the past decade.

Liqi Chen (Key Lab of Global Change and Marine-Atmospheeric Chemistry, China) followed on by examining changes in surface pCO_s in the western Arctic Ocean, in particular the implications of shrinking sea-ice extent. The paper was based on five Chinese Arctic cruises from 1999-2010. Over this period, the expeditions progressively reached further north due to the shrinking sea ice. Very low pCO_2 is found under the sea ice but high values, almost as high as in the air, in exposed surface waters due to uptake from the atmosphere. This could accelerate the negative impact of ocean acidification in Arctic ecosystems. A mixing model was developed for CO_2 in the W Arctic based on exchanges with the Bering Sea. Surface acidification was caused by both biological recycling and uptake of atmospheric CO_2. The increased uptake by the Arctic may provide a negative feedback to the buildup of CO_2 in the atmosphere.

The next paper by Takamitsu Ito (Georgia Institute of Technology, USA)) and Curtis Deutsch (University of California, LA, USA) was delivered by Deutsch due to the early departure of Ito. The paper examined decadal-scale trends in the expansion and contraction of the oxygen minimum zone (OMZ) in relation to

changing respiration. Using time series from the Eastern Tropical Pacific (ETP) from 1960-2000, recent work by Stramma et al. showed expansion of the OMZ in the last 20 years. Ito and Deutsch used CalCOFI data to develop a global ocean biogeochemical model, which focused on the ETP. The model showed contraction of the OMZ in the 1970s but expansion in the recent past. The volume of suboxic water varied considerably with multidecadal variability and the influence of major El Ninos. The apparent oxygen utilization (AOU) is the major contributor to the pattern. Transport was dominated by the Equatorial Undercurrent. Respiration shows a positive trend highly correlated with warming and dominates. The model indicates there are two competing effects. El Nino leads to weaker transport of low-O_2 water, but also less upwelling and hence less productivity. But the overall effect is increased O_2 due to decreased upwelling. La Nina however leads to OMZ expansion. The thermocline water has a kind of memory that integrates the ENSO signals to a PDO, or multidecadal signal.

The next paper presented by Shuchai Gan (East China Normal University, China) examined patterns of bio-available dissolved organic carbon (BDOC) of different water masses in the East China Sea. DOC comprises the largest carbon pool in the ocean: 1% is equivalent to 1 year's fossil fuel combustion. Micro-organisms are major consumers of DOC. But much is refractory and this portion of the C cycle is poorly understood. There are several water masses in the East China Sea, including coastal and oceanic water and water with Yangtze River influence. As they showed, each water mass may had a distinct chemistry with different labile and non-labile components with different bioavailability.

Kosei Komatsu (University of Tokyo, Japan) and colleagues used historical observations and survey data to investigate nutrient transport within the Kuroshio Current and its impacts on regional productivity. They found maximum nutrient concentrations within the Kuroshio jet at levels between 24.5-26.0 s_q, with a structure similar to that seen in the Gulf Stream. Evidence of high epipycnal and diapycnal fluxes were observed, the latter contributing significantly to spring new production in adjacent regions.

Jim Christian (Fisheries and Oceans Canada) and colleagues compared patterns and trends in ocean calcite and aragonite saturation states from a suite of CMIP5 Earth System Models. Each of the 7 models compared demonstrated strengths and weaknesses when compared to observations, emphasizing the need to use multiple models. They found an order of magnitude increase by 2100 in total area of shallow aragonite saturation in all models under the "no mitigation" scenario, although this depended strongly on the rate of CO_2 increase. All models underestimated the North Pacific contribution to the growth of the area of shallow undersaturation.

Silvana Birchenough (Lowestoft, UK) and colleagues showed how a sediment profile imagery camera could be used to characterize benthic communities and their sedimentary characteristics in areas adjoining cold-water coral reefs, which are subject to potential stress due to ocean acidification. They demonstrated the use of the camera system based on a cruise to the Outer Hebrides and Banana reef complex and the Logachev Mounds in the northeast Atlantic. Distinct benthic communities and sediments were found at each site, and the work showed the potential of the camera system to explore these habitats and develop time series to assess the potential impacts of acidification on a diverse deepwater habitat.

Jack_Barth (Oregon State University, USA) and colleagues described patterns of hypoxia on the Oregon continental shelf from a suite of instruments including buoys, moorings, gliders, and ship-based surveys, as well as historical hydrographic observations. They described significant interannual variability in the timing, intensity and spatial distribution of hypoxia on the inner shelf, including the appearance of anoxia in summer 2006. A simple model driven by local wind forcing and source water dissolved oxygen levels explains 80% of the variability in near-bottom, inner shelf dissolved oxygen. Based on projected changes in source water dissolved oxygen, they estimated that the frequency of inner shelf hypoxia during the summer upwelling season could increase to 90%, comparable to the persistent hypoxic conditions found in the Humboldt Current.

Yvette Spitz (Oregon State University, USA) presented a paper by herself and Harold Batchelder based on a coupled ecosytem-ROMS modeling approach to investigating dissolved oxygen dynamcs on the Oregon continenal shelf and cross-shelf exchanges. They presented a model hindcast for three years (2002, 2006, 2008) that had different forcing and displayed different patterns of hypoxia. The model reproduced the

observed interannual variability quite well, but they found that their results were highly sensitive to initial and boundary conditions.

Curtis Deutsch (University of California, LA, USA) presented an invited talk on organisms' metabolic constraints related to oxygen requirements and the potential impacts of climate change. They presented a metabolic index based on the ratio of O_2 supply and demand. They compiled laboratory studies for a range of organisms to show that despite a wide range of thermal and hypoxic tolerances, the contemporary range of the investigated species was bounded by a similar metabolic index. Changing climate will thus impose a fundamental metabolic constraint on their habitat. Marine organisms (unlike terrestrial organisms) are generally metabolically constrained at the equatorial edge of their range. Habitats will generally shrink in the future with warmer and deoxygenated water.

Brad Seibel (University of Rhode Island, USA) changed the title of his invited talk to "Existing oxygen levels are the critical oxygen levels." He presented a range of field and laboratory studies identifying the critical oxygen levels for marine animals that depends on temperature and other environmental factors. He showed the adaptations of mesopelagic organisms to low oxygen concentrations but showed that many of those organisms were already living at the limits of their oxygen and temperature tolerances. Thus future potential changes due to warming, acidification, and deoxygenation could have dramatic impacts on midwater communities.

Angelica Pena and William Crawford (Fisheries and Oceans Canada) showed the long-term trend of dissolved oxygen in the ocean interior off the west coast of Canada. Pena examined oxygen time series on the shelf as well as at OWS Papa. She demonstrated that the decadal pattern on the shelf matched that observed in the southern California Current with dissolved oxygen level low around 1960, increasing in the mid-1980s, and decreasing significantly in the last decade. The pattern in the open waters of the Gulf of Alaska shows a different pattern, exhibiting a monotonic decline.

Yukihiro Nojiri (National Institute for Environmental Studies, Japan) and colleagues presented a paper on the variability cof the arbon cycle and biological production in the North Pacific estimated from mapping pCO_2, alkalinity, and dissolved inorganic carbon. Observations of ocean surface PCO_2 were collected as part of the NIES programme. The presentation showed a climatology map including DIC values, demonstrating a decrease in concentration during the summer season, mainly related to the community productivity at the ocean surface. DIC changes were observed in some areas. The main conclusion were that: i) DIC distribution has higher spatial variation and can be analyzed with neural networks, including pCO_2 mapping and ii) the maps could be compared against the oceanic variability such as ENSO and/or PDO to estimate the influence of these oceanic patterns on biological production to understand the impact of PDO on the changing DIC distribution.

Keith Rodgers (Princeton University, USA) and colleagues presented a paper on the re-emergence of anthropogenic carbon and Pacific pool acidification. They presented a model to test the hypothesis that meridian overturning of the Pacific subtropical cell controls the supply of anthropogenic DIC to the Pacific warms pool. The model results agreed well with the results presented by Ishii (2009). The upwelling of thermocline waters rich in anthropogenic carbon in the cold tongue regions serves as a "re-emergence" of anthropogenic carbon. Some of this work suggests that re-emergence is a first order, if not dominant, driver of the acidification of equatorial Pacific warm pool waters.

Finlay Scott (Lowestoft, UK) and colleagues prepared a paper on predicting the regional impacts of ocean acidification based on integrating sediment biodiversity and ecosystem function. The effects of ocean acidification for benthic species were developed in a model to examine faunal responses. A Biological Traits approach (BTA) was used to code the species based on their sensitivity. The North Sea benthos 1986 survey was used since biomass and abundance were available and the data was used to calculate a Bioturbation potential index. The use of Chl and organic carbon to characterize the areas was also examined in relation to the index values. A series of histograms were used to examine changes by area and to explore the importance of sensitive species in those areas. The work is still under development.

Tony Koslow (Scripps Institution of Oceanography, USA) and colleagues presented a talk on **t**he influence of declining oxygen concentration on mesopelagic fish biomass in the California Current and the potential impacts on ecosystems structure. CalCOFI ichthyoplankton and environmental data were used to show a close relationship between decadal changes in midwater oxygen concentration and the abundance of wide range of mesopelagic fishes in the California current. Changes in the mesopelagic fishes were correlated as well with large-scale environmental indices, such as the ENSO and PDO on the one hand and with fluctuations of dominant epipelagic planktivores (anchovy, hake, and mackerel) on the other. The abundance of both mesopelagic migrators and total meso- and epipelagic planktivores wre negatively correlated with the abundane of key plankton groups. However, the correlation seemed to be mediated by common correlations with environmental forcing, such as the strength of the California Current.

Julie Keister (University of Washington) and colleagues presented a paper on **o**xygen and pH conditions experienced by zooplankton in Puget Sound. Field and laboratory results were combined to study the relationship between ocean chemistry and zooplankton distribution, focusing primarily on areas with particularly extreme oxygen and acidification conditions. Experiments examined the influence of hypoxia on developmental rate, hatching success and mortality. This information has the potential to be used to model the future for coastal ocean ecosystems under conditions of increasing oxygen and acidification stress.