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Ocean acidification along the Gulf Coast and East Coast of the USA

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ABSTRACT

As part of an effort to monitor changes in inorganic carbon chemistry of the coastal ocean, near-synoptic cruises are being conducted in the Northern Gulf of Mexico and along the East Coast of the United States. Here we describe observations obtained on a cruise in the summer of 2012 and compare them with results from a cruise following a similar track in 2007. The focus is on describing spatial patterns of aragonite saturation state (Ω_{Ar}). This parameter is an indicator of ecosystem health, in particular for calcifying organisms. The results show large-scale regional trends from different source waters at the northeastern and southwestern edges of the domain, along with the modulating effects of remineralization/respiration and riverine inputs. The broader patterns and changes over five years along the coast can be well described by the impacts of large-scale circulation, notably changes in source water contributions. Changes in the well-buffered Loop Current and Gulf Stream with high Ω_{Ar} impact the waters in the southern part of the study area. The less buffered southward coastal currents with low Ω_{Ar} originating from the Labrador Sea and Gulf of St. Lawrence impact the Ω_{Ar} patterns in the Northern regions. The expected 2% average decrease in Ω_{Ar} in the surface mixed layer due to increasing atmospheric CO_2 levels over the 5-year period is largely overshadowed by local and regional variability from changes in hydrography and mixed layer dynamics.

1. Introduction

Changes in the inorganic carbon chemistry of seawater due to invasion of anthropogenic carbon dioxide (CO_2) from the atmosphere is referred to as ocean acidification (OA). The increase of surface water CO_2 leads to a decrease in the buffering capacity of the ocean due to loss of carbonate ions (CO_3^{2-}) following the stoichiometry shown in Eq. (1).

$$CO_2 + CO_3^{2-} + H_2O = 2\ HCO_3^- \quad (1)$$

This decrease of CO_3^{2-} has a direct impact on the growth and survival of calcifying organisms. Other changes associated with increasing atmospheric CO_2 levels and uptake of the excess CO_2 by the ocean, such as increases in the hydrogen ion concentration and increasing partial pressure of CO_2, impact a variety of organisms as well (Wittmann and Portner, 2013).

Increases in surface water CO_2 levels dependably follow increasing atmospheric levels, particularly in the open ocean. While deviations from these trends can have impacts on global ocean carbon uptake on seasonal to interannual scales (Le Quéré et al., 2010; Takahashi et al., 2009; Wanninkhof et al., 2013), they generally do not have appreciable impacts on global OA trends within the current uncertainty of measurements. Locally, and particularly in the coastal ocean and nearshore, there are several confounding effects that can impact ocean acidification. These processes affect the inorganic carbon speciation shown in Eq. (1) and are often included in a broader description of OA. The processes effecting OA, and OA changes and trends in the coastal oceans must be monitored and understood as most of the commercial and recreational fisheries and aquaculture industries occur near the coast.

Effects that modulate the general trend of ocean acidification include respiration and remineralization of organic matter, releasing CO_2 in the aquatic environment (Cai et al., 2011). These processes are generally associated with oxygen drawdown, which in stratified waters can lead to hypoxia and have detrimental influences on ocean biota as well (Zhang et al., 2013; Rabalais et al., 2014). Upwelling of water with high CO_2 levels can have a

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large effect on OA both as a direct influence and because upwelled CO_2-rich water is less buffered such that invasion of anthropogenic CO_2 causes an enhanced decrease in CO_3^{2-} (Feely et al., 2008; Harris et al., 2013). Continental contributions from rivers, swamplands, estuaries, and groundwater inputs can also have appreciable and variable impacts, and these effects are often measured along the salinity gradients from continental sources to the coastal ocean (Cai and Lohrenz, 2007; Cai et al., 2010; Huang et al., 2015; Liu et al., 2014; Salisbury and Green, 2008). Such impacts are expected to be particularly significant for rivers with low alkalinity and thus weak buffer capacity (Hu and Cai, 2013).

In response to the threats of ocean acidification and confounding factors, the Ocean Acidification Program (OAP) of the National Oceanic and Atmospheric Administration (NOAA) has been charged with setting up an ocean acidification monitoring network to quantify the increase in near surface water CO_2 (and decrease in pH) and associated changes in inorganic carbon speciation. As part of the observing scheme, dedicated research cruises are conducted to investigate the water column properties along select transects, and pertinent surface water characteristics are evaluated along the cruise track.

The second Gulf of Mexico and East Coast Carbon Cruise (GOMECC-2) took place on NOAA ship *Ronald H. Brown* from July 21 through August 13, 2012 with 8 cross-shelf transects in the Gulf of Mexico (GOM) and East Coast of the United States covering distinct biogeochemical regimes. The overall characteristics of the regions are described in Wang et al. (2013) based on the first GOMECC study in 2007. From the Louisiana line to the Cape Hatteras line (Fig. 1), the study region is bounded by the Loop Current, Florida Current, and Gulf Stream system. These waters serve as endmembers in coastal mixing dynamics and act as a conduit for northward movement of chemical constituents that originate from the adjacent coastal seas and gyres. To the north of Cape Hatteras, impacts of the Labrador Sea slope water and associated coastal jets prevail in coastal waters (Fratantoni and Pickart, 2007; Han et al., 2014). The data from the GOMECC-2 cruise are used to describe the state of the inorganic carbon system in this realm and, in combination with the GOMECC-1 data, are used to evaluate differences over the last 5 years. Our discussion is focused on the dynamics of the aragonite saturation state (Ω_{Ar}) as a prime indicator of OA. The GOMECC-2 data are used to show spatial distributions in this parameter, and with data from GOMECC-1 provide a comparison of Ω_{Ar} between the summers of 2007 and 2012.

While different organisms have varying sensitivities to the different forms of inorganic carbon, their sensitivities can often be categorized by the physical and chemical state of seawater, in particular Ω_{Ar}. The Ω_{Ar} is a primary control on calcifying rates and the mortality of calcifying organisms (Andersson, 2014; Waldbusser et al., 2015). The Ω_{Ar} can also serve as an indicator of the state of the inorganic carbon system, encompassing alkalinity (TAlk), total dissolved inorganic carbon (DIC), salinity, temperature and pressure effects.

The Ω_{Ar} is not measured directly but is calculated from observed variables. It is defined as the product of calcium and carbonate ion concentrations divided by the solubility product of the calcium carbonate mineral phase aragonite:

$$\Omega_{Ar} = [Ca^{2+}]\,[CO_3^{2-}]\,(K'_{Ar\ spP})^{-1} \quad (2)$$

where $[Ca^{2+}]$ is the total calcium concentration and is derived from salinity. It is based on the constancy of composition of major cations in seawater. The $[CO_3^{2-}]$ is the total carbonate ion concentration determined from two of the four measured inorganic carbon system parameters, and $K'_{Ar\ spP}$ is the apparent solubility product of the calcium carbonate mineral phase aragonite in seawater at a specified salinity, temperature and pressure. If Ω_{Ar} is less than one, the mineral phase is thermodynamically unstable.

Here we investigate the surface and subsurface patterns of Ω_{Ar} along the Gulf Coast and East Coast of the United States and factors that influence it. The sensitivity and uncertainty of the calculations are discussed. The geographical and temporal variations of Ω_{Ar} are presented along with the confounding effects of continental inputs and remineralization. Following Wang et al. (2013) the Gulf Stream is used as a demarcation in the coastal region up to Cape Hatteras,

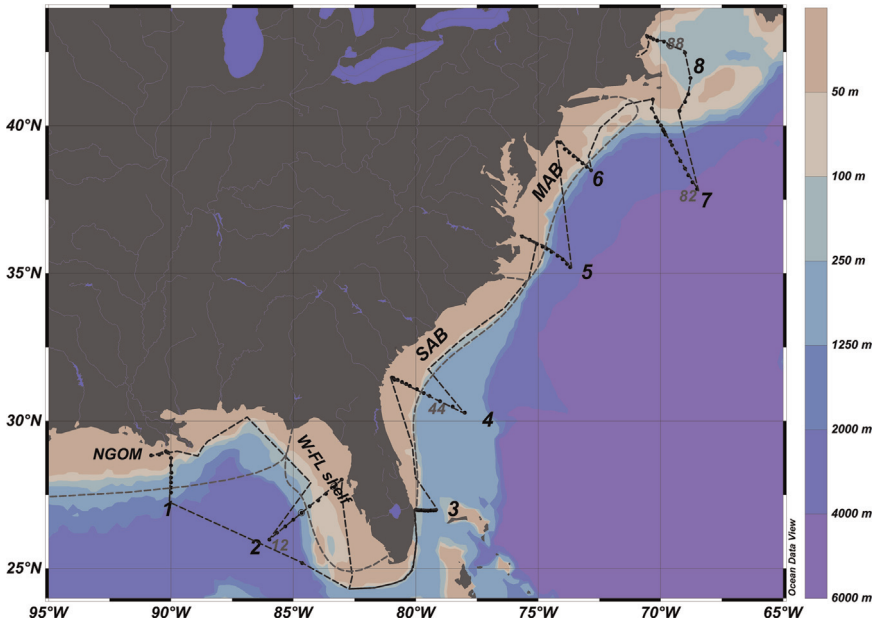

Fig. 1. Map of the study area. The cruise track for the GOMECC-2 cruise is the black dashed line and CTD station locations are the black circles. The gray numbers are the station numbers described in Fig. 2. The bathymetry is a color scale with the legend at the right. The areas of the Northern Gulf of Mexico (NGOM), West Florida Shelf (W-FL shelf), South Atlantic Bight (SAB) and Mid Atlantic Bight (MAB) are delineated by the dashed gray lines. The black numbers identify the different transects: (1) Louisiana, LA line, (2) Tampa line, (3) 27°N line, (4) Georgia, GA line, (5) Cape Hatteras line, (6) New Jersey, NJ line, (7) Line W, and (8) New Hampshire, NH line. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)