Deep-Sea Research II 102 (2014) 77–83

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Dinitrogen, oxygen, and nutrient fluxes at the sediment–water interface and bottom water physical mixing on the eastern Chukchi Sea shelf

Afonso C. Souza *, Il-Nam Kim, Wayne S. Gardner, Kenneth H. Dunton

Marine Science Institute, The University of Texas at Austin, 750 Channel View Dr., Port Aransas, TX 78373, USA

ARTICLE INFO

Available online 9 January 2014

Keywords:
Mixing ratio
Sediments
Benthic fluxes
Nutrients
Nitrogen
Chukchi Sea

ABSTRACT

We measured fluxes of net dissolved N_2 and O_2, NO_3^-, and PO_4^{-3} at the sediment–water interface in whole cores in relation to bottom water temperature and salinity in late summer 2010 on the shelf of the eastern Chukchi Sea. Cold (−1.68 °C) and high-salinity (33.72) bottom water, characteristic of Pacific winter water, overlaid the sediment over the northeastern region of the shelf while relatively warmer (8.33 °C) and less saline (29.88) water with properties of Alaska Coastal Water covered the seabed in the southeastern region. Latitudinal variability of gas fluxes was not linked to differences in temperature or salinity. Relatively higher N_2 efflux was measured for sediment located at the water mixing front between cold and warm bottom waters. Benthic O_2 consumption in the southeastern region was relatively intense as were NO_3^- and PO_4^{-3} effluxes from the sediments into the water column. Overall, sediments in the Chukchi Sea are sites of intense denitrification but these losses appear compensated by benthic NO_3^- regeneration, as NO_3^- efflux from sediments into the overlying water exceed those of N_2. Exposure of sediment cores to incoming light did not affect benthic fluxes significantly compared to dark conditions.

1. Introduction

The broad continental shelf of the Chukchi Sea is one of the most productive regions in the Arctic Ocean (Sakshaug, 2004). Maximum shelf primary productivity is 2.5 g C m^{-2} day^{-1} (Gosselin et al., 1997) and benthic secondary standing stocks range from 360 to 4000 g m^{-2} (Dunton et al., 2005; Grebmeier et al., 2006). Benthic infaunal biomass and primary productivity vary spatially (Dunton et al., 2005; Grebmeier et al., 2006), due in part to water column characteristics such as temperature and nutrient availability (Springer and McRoy, 1993). Additional factors driving spatial variability of benthic biomass include the advection of nutrient-rich Pacific water (Codispoti et al., 2005; Walsh et al., 1989), seasonality, and structure of this Pacific water inflow (Woodgate et al., 2006, 2005).

Three main water masses flow northward through the Bering Strait and fan out across the Chukchi shelf. The Alaskan Coastal Water on the east is relatively warm ($T > 4$ °C) and fresh ($S < 31.8$) compared to the centrally flowing Bering Shelf Water ($T = 0$–1.5 °C; $S = 31.8$–32.5) and cold and salty Anadyr Water ($T = -1.0$–1.5 °C; $S > 32.5$) that flows along the western portion of the strait (Coachman and Aagaard, 1988; Coachman et al., 1975; Walsh et al., 1989). Remnant winter-transformed Pacific water from the previous winter also transits over the shelf (Coachman and Barnes, 1961; Weingartner et al., 1998; Spall, 2007). Winter water-masses can have high salinities (>33) depending on the vigor of ice formation in coastal polynyas (Weingartner et al., 2005).

The relationship between infaunal biomass distribution and overlying water characteristics is quite well understood in this region of the Chukchi Sea (Grebmeier et al., 2006); however the spatial variability of benthic microbial processes controlling the fate of nitrogen relative to water properties has not been described comprehensively. Denitrification, for example, is an important sink for nitrogen, but has not been measured extensively in the Chukchi (Chang and Devol, 2009). The removal of N acts as a negative feedback to primary production by affecting the net rate of NH_4^+/NO_3^- regeneration at the sediment–water-interface. Denitrification in Chukchi Sea sediments could be responsible for the nitrogen deficit relative to phosphate (PO_4^{-3}) on the Canada Abyssal Plain (Codispoti et al., 2005). Spatial variability of dinitrogen gas (N_2) flux is large over the Chukchi Sea shelf, ranging from 0.49 to 2.8 mmol N m^{-2} d^{-1} with an average of 0.96 mmol N m^{-2} d^{-1} (Devol et al., 1997).

Information on benthic flux of nitrogenous species is limited in the Arctic compared to other environments (e.g. Hou et al., 2012; Lin et al., 2011; Codispoti 2007). Few studies present recent values

* Corresponding author. Tel.: +1 361 749 6773; fax: +1 361 749 6777.
E-mail address: szafo224@gmail.com (A.C. Souza).

0967-0645/$ - see front matter
http://dx.doi.org/10.1016/j.dsr2.2014.01.002

for nutrient and dinitrogen gas fluxes in Chukchi Sea sediments (Chang and Devol, 2009; Christensen 2008) following the initial work by Devol et al. (1997). Determination of baseline values for benthic fluxes and transformations of N species is important in considering the progressive climatic changes occurring in the arctic region. Accordingly, more extensive and up-to-date measurements of oceanic N_2 production are needed to understand the large deficit in the global N budget caused by a much larger sink than apparent sources (Codispoti, 2007). The overarching goal of this research is to quantify N_2 flux in sediments to provide relevant mechanistic insights relating to N cycling in the Chukchi Sea. Specific objectives are to: (1) identify the geographical distribution of water physical characteristics overlaying the sediments over the study area, (2) determine the spatial variability of benthic biogeochemical processes with latitude by measuring net fluxes of NO_3^-, PO_4^{-3}, O_2, and N_2 at the sediment–water interface, and (3) assess their potential connection to bottom water physical properties overlaying the Chukchi Sea shelf. Light and dark incubations were conducted to explore O_2 flux differences attributable to potential benthic photosynthetic activity in these regions.

Two specific hypotheses were examined:

1. *Benthic net N_2, O_2, NO_3^-, and PO_4^{-3} fluxes are highest at stations influenced by Bering Shelf Water.* This hypothesis is based on: (1) the relatively high nutrient and warm temperature signature of Bering shelf water in the southern region of the Chukchi Sea (Walsh et al., 1989), (2) the geographical distributions of sediment organic matter content (Grebmeier et al., 1995; Naidu et al., 2003), and (3) the high water column primary productivity and benthic faunal abundance (Dunton et al., 2005; Grebmeier et al., 2006), which are consistently higher in the southeastern Chukchi Sea than in other regions.
2. *Lower nutrient efflux and oxygen consumption will occur in cores under natural light than in dark conditions.* This expected pattern may result from nutrient consumption and oxygen production by benthic primary producers.

2. Material and methods

2.1. Sample collection and pretreatment

This study was part of the Chukchi Sea Offshore Monitoring in Drilling Area-Chemical and Benthos (COMIDA CAB) program. The COMIDA CAB study area is located in the Northeastern Chukchi Sea shelf (Fig. 1). Sample collections were conducted during the summer field season aboard the R/V Moana Wave from July 25 to August 11, 2010. Sediment was sampled at four stations (S1–S4), one on the southern Chukchi shelf at 68°N and the remaining three along an E–W transect along the 71°N line of latitude. Seawater temperature and salinity were measured at 23 stations using a YSI 650MDS sonde (YSI Inc., Yellow Springs, OH), with a resolution of 0.01 parameter units. The accuracy of temperature and conductivity measurements were ± 0.15 °C and ± 0.001 mS cm^{-1}, respectively. Prior to deployment, the salinity probe was calibrated using a conductivity/TDS 50,000 micromhos cm^{-1} NaCl standard solution (30.300 ppt; Ricca Chemical Co., part# 2248-32). Following removal of occasional spurious data points attributed directly to instrumental error, the acquired T and S data were averaged at intervals of 1 m along the depth gradient.

Concentrations of N_2, O_2, NO_3^-, and PO_4^{-3} were measured in continuous flow experiments with "intact" sediment cores (An et al., 2001; Lin et al., 2011) collected using a "HYPOX" corer (Gardner et al., 2009). Circulating seawater pumped from the ocean surface maintained two replicate intact cores at a relatively constant ± 1 °C for an incubation period of 3 days during which one set of replicate cores was exposed to incoming ambient light (500–1300 μmol m^{-2} s^{-1}) and another set kept dark under a tent of aluminum foil. Cores were capped with an acetol plunger through which one inflow and one outflow peek line were connected and a Viton o-ring was used to seal the core. The plunger was positioned about 5 cm above the sediment surface creating a 230 ml overlying water volume. A multi-channel peristaltic pump circulated seawater from the station (stored in 20-L jugs) over the sediment at a rate of 0.9 ml min^{-1} (Gardner et al., 2006). Fluxes were calculated from the differences between concentrations of constituents in inflow and outflow samples at the same time point. The cores were allowed to "equilibrate" for 24 h with overflowing seawater before two replicate water samples were collected for analysis from each inflow and outflow line on the second and third day of incubation. Samples for gas analysis were preserved unfiltered with 100 μL $ZnCl_2$ (50% saturation w/v) in capped 15 ml glass vials stored in sealed containers and submersed in cold seawater. One water sample per core for each 24-h time point was collected for nutrient analysis from the outflow line of each core and from the inflow line. Nutrient samples were filtered immediately through 0.2 μm pore size syringe filters and the filtrates kept frozen in 15 mL centrifuge tubes until analysis. Vials for gases were transported submersed in cold seawater inside capped plastic jugs placed inside coolers until analysis at The University of Texas Marine Science Institute (UTMSI) using a Membrane Inlet Mass Spectrometer (MIMS; An et al., 2001). The coefficients of variation (standard deviation of the mean) in standards were 0.1% for dissolved N_2 and 0.3% for dissolved O_2 ($n=10$). Nitrate and PO_4^{-3} concentrations of each vial were measured twice using a Lachat Quikchem 8000 Flow injection analysis system. The coefficients of variation in three replicate NO_3^- and PO_4^{-3} standard solutions were 1%.

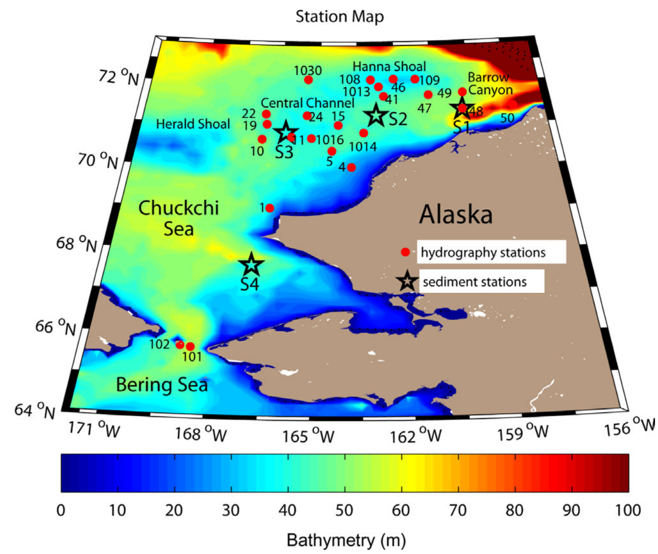

Fig. 1. Bathymetry in meters and station locations for hydrography (red dots) and sediment process studies (black stars) in the northeastern Chukchi Sea study area. Corresponding station numbers (S1–S4) for the four sediment process study stations are: S1 (48), S2 (1015), S3 (9), and S4 (103).

2.2. Mixing model configuration

Four different end-members were distinguished in the study area and separated based on their physical characteristics (Fig. 2 and Table 1). A four end-member mixing model was therefore used to estimate the mixing ratios among end-members