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Acoustic backscatter observations with implications for seasonal and vertical migrations of zooplankton and nekton in the Amundsen shelf (Antarctica)

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ABSTRACT

High-temporal resolution profiles of acoustic backscatter were collected in the Dotson Trough on the Amundsen shelf in the Antarctica, using a bottom-moored, upward-looking acoustic Doppler current profiler (ADCP). This data set was used to examine the impact of seasonal variations in surface solar radiation (SSR), sea ice concentration (SIC), and Circumpolar Deep Water (CDW) thickness on acoustic backscatter in the lower water column (250–540-m depth). A recorded high acoustic backscatter (−75 to −70 dB) at depth >400 m from April to November compared to the rest of the year (−90 to −80 dB) suggests that zooplankton and nekton migrated towards the bottom during winter. The depth of maximum mean volume backscattering strength showed a significant correlation with SSR, SIC and CDW thickness. A daily cycle of vertical migration was also recorded. This varied with changing surface ice conditions. When sea ice cover was low, the acoustic backscatter descended at sunrise, and ascended at sunset. When sea ice cover was high, the daily migration was not pronounced, and the layer of high acoustic backscatter remained near the bottom. This is the first study of seasonal and vertical migration of zooplankton and nekton that has been conducted on the Amundsen Sea shelf, one of the world's most productive areas. The findings provide implications to understand the behavior of zooplankton and nekton below the euphotic zone in the Southern Ocean.

1. Introduction

The acoustic Doppler current profiler (ADCP) is an important tool used to study not only velocity profiles (Schott, 1986; Kaneko et al., 1990; Shin et al., 2006; Kang et al., 2012) but also acoustic backscatter from marine organisms (e.g., zooplankton and nekton) (Flagg and Smith, 1989; Zimmerman and Biggs, 1999; Wade and Heywood, 2001; Lu et al., 2007; Benoit et al., 2008; Geoffroy et al., 2011). The ADCP has helped determine the spatial and temporal distributions of zooplankton in many regions (Plueddemann and Pinkel, 1989; Zhou et al., 1994; Blachowiak-Samolyk et al., 2006; Brierley et al., 2006; van Haren, 2007; Berge et al., 2009; Cisewski et al., 2010; Wallace et al., 2010). Using moored ADCPs, seasonal and inter-annual patterns and diel vertical migration (DVM) of zooplankton have been monitored over long-term periods, providing insight into the possible causes of variation in these factors, which would be unattainable with regular ship-based samplings (van Haren, 2007; Cisewski et al., 2010; Wallace et al., 2010).

Vertical migration is a common behavior exhibited by zooplankton, and it may be caused by predator avoidance (Zaret and Suffern, 1976; Bollens et al., 1992; Fortier et al., 2001), phytoplankton distribution (Thorisson, 2006), and biorhythm (Hays, 2003). It is also reported to be triggered by variations in light intensity (Forward, 1988; Ringelberg, 1995). As vertical migration occurs on diel, seasonal and inter-annual time scales, long-term observational data with high-temporal resolution is needed to study the characteristic patterns of vertical migration over the entire temporal range. Long-term observations can also help understand the effects on vertical migration of environmental changes including global climate change and the cycling of carbon and nutrients (Al-Mutairi and Landry, 2001; Steinberg et al., 2002).

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Despite many decades of research on vertical migration, our understanding on the role of environmental factors (e.g., light and sea ice) in Polar Oceans is still limited. This is mainly because the harsh weather and sea ice limit the access to areas where long-term observational data is necessary. The lack of such data has impeded our evaluation and prediction of the zooplankton life cycle in Polar Oceans, where sea ice concentration (SIC) might affect vertical migration patterns.

To better understand vertical migration, an ADCP was moored in the Dotson Trough on the Amundsen shelf in Antarctica (Fig. 1). The Amundsen Sea is one of the most productive regions in the Southern Ocean, and extensive phytoplankton blooms have been consistently detected during austral summer via satellite-based ocean color sensors (Arrigo and van Dijken, 2003; Arrigo et al., 2012). This sea is ideal for observing the seasonal variability of acoustic backscatter because of the region's rapid variation in SIC as well as its high productivity. The aim of this study is to provide the assessment of the seasonal and vertical migration of acoustic backscatter as a proxy for abundance/biomass of zooplankton and nekton below the euphotic zone in seasonally ice-covered region. It would have been preferable to have ground-truth data (e.g., by net sampling) to verify the linkage between acoustic backscatter and zooplankton/nekton abundance. Clearly it is not possible to perform continuous net samplings for one year in this region but make the reasonable guess on migrating behaviors for various species. It is convinced that the present acoustic data set could provide implications for the diel and seasonal migration of zooplankton and nekton from one of the most hostile and under-sampled places on Earth.

2. Materials and methods

2.1. Mooring location

The mooring system was installed on the eastern side of the Dotson Trough (72°27.35′S, 116°20.33′W) in the Amundsen Sea during the *Oden* OSO0910 cruise (February 16, 2010), and then recovered during the *Araon* ANA01C cruise (December 25, 2010) (Fig. 1). The Amundsen Sea has been the focus of studies on the accelerated thinning of glaciers caused by warm, salty water beneath the ice shelves (Walker et al., 2007; Arneborg et al., 2012; Pritchard et al., 2012; Wåhlin et al., 2012, 2013; Ha et al., 2014). This warm water mass is derived from Circumpolar Deep Water (CDW; upper boundary was defined by 0 °C isotherm) (Wåhlin et al., 2010; Jacobs et al., 2012), a voluminous water mass found off the continental shelves around Antarctica (Orsi et al., 1995). The Dotson Trough provides a major conduit for the delivery of large volumes of CDW onto the shelf, with the main pathway of CDW inflow along the trough's eastern side (Ha et al., 2014). CDW above 0.6 °C flowed persistently in the Dotson Trough during the sampling period (2010–2012), and its thickness and temperature peaked in late summer and early fall (Wåhlin et al., 2013). The depth-averaged along-trough velocity during this period was about 0.024 m s^{-1} (Wåhlin et al., 2013).

2.2. Data collection

The mooring was equipped with a 150-kHz ADCP (RDI, Workhorse Quartermaster) and an array of five MicroCats measuring conductivity, temperature, and pressure (Seabird, SBE-37) from the

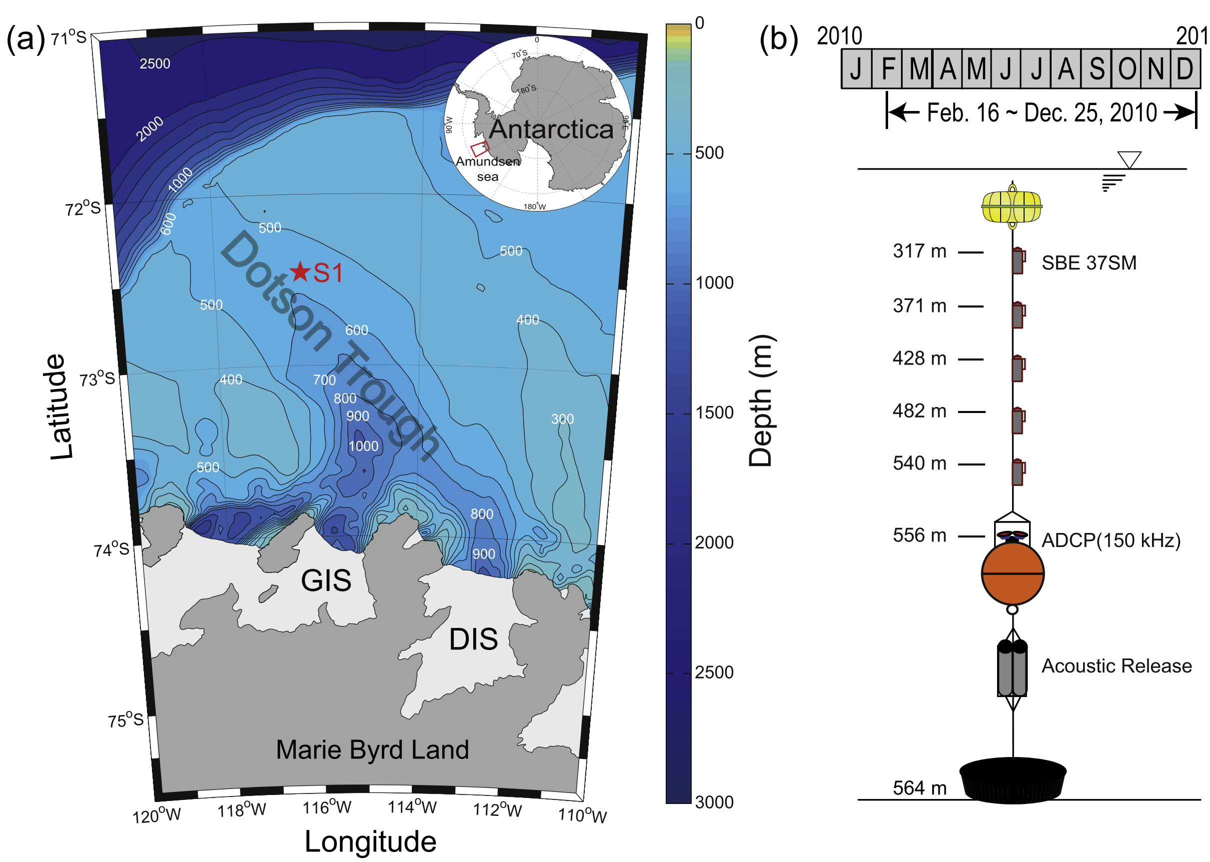

Fig. 1. (a) Map of the study area. The star (S1) indicates the mooring location (72°27.35′S, 116°20.33′W). (b) Design of the mooring system. GIS: Getz Ice Shelf; DIS: Dotson Ice Shelf.