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Surface water $\delta^{18}O$ in the marginal China seas and its hydrological implications

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ABSTRACT

Surface water $\delta^{18}O$ distribution in the marginal China seas (including the south Yellow and East China Seas, YECS, and the northern South China Sea, NSCS) and its relationship with salinity were investigated to gain insight into the surface hydrological processes in these seas. In the YECS where $\delta^{18}O$ and salinity varied in relatively large ranges, seasonally different slopes of $\delta^{18}O$-salinity linear fits, i.e. 0.26 ± 0.02 in summer and 0.23 ± 0.01 in winter, were observed. In the NSCS, $\delta^{18}O$ and salinity ranged narrower than in the YECS, and exhibited a similar linear relationship in winter but a poor correlation in summer. The saline surface water end-members were nearly identical in $\delta^{18}O$ and salinity in both the YECS and NSCS and showed different values between summer and winter. These saline end-members were distinct from the reported values of the Kuroshio water (KW), which might be related to modification of KW mainly by atmospheric forcing. Using a simple mixing model, we showed that the observed significant linear $\delta^{18}O$-salinity relationships in the YECS were caused mainly by great terrestrial freshwater influx. The observed poor correlation between $\delta^{18}O$ and salinity in the summer NSCS was likely associated with the relatively minor runoff contribution, although in wet period, to the freshwater end-member. The still good relationship in the NSCS during the dry wintertime, however, was attributable to the strong China Coastal Current flowing from the ECS to the NSCS through the Taiwan Strait driven by the prevailing northeast monsoon.

1. Introduction

Marginal seas are important transit zones for the exchange of materials between land and ocean, and they are usually active in air-sea interaction. Despite their moderately-sized surface areas, marginal seas play a crucial role in the ocean carbon cycling and other biogeochemical processes (Dagg et al., 2004; Muller-Karger et al., 2005). A thorough knowledge of the surface hydrological processes along the marginal seas is a primary requirement for understanding ocean circulation, biogeochemical cycling and ecosystem dynamics. Studies over the past decades have shown that marginal seas around the world are experiencing rapid climate change, and consequently the freshwater budgets in these regions are significantly affected (Belkin, 2009; Helm et al., 2010), which is needed to be documented to better understand its consequences.

The stable oxygen isotopic composition ($\delta^{18}O$) is an important tracer of natural hydrological processes. It is imprinted on a water mass in its source area and, once isolated from the surface ocean, altered only by conservative mixing with other water masses of contrasting composition (Craig and Gordon, 1965; Frew et al., 2000). Thus, in modern ocean research, $\delta^{18}O$ measurements have been used to obtain valuable information on the origin and mixing of water masses (e.g., Torgersen, 1979; Zhang et al., 1990; Frew et al., 2000). Besides, a parallel study of $\delta^{18}O$ and surface seawater salinity (SSS) can also provide specific information about sea surface hydrological processes such as (1) evaporation/precipitation, (2) melting/freezing, (3) upwelling/advection, and (4) continental runoff (Craig and Gordon, 1965; Benway and Mix, 2004). Furthermore, the $\delta^{18}O$-SSS relationship has been widely used in paleoclimatology/paleoceanography to determine past SSS changes from the $\delta^{18}O$ measurements of carbonate shells of marine microfossils such as foraminifera (e.g., Rohling, 2000; Jia et al., 2006; Yu et al., 2009).

The marginal seas off China, e.g., the Yellow and East China Seas (YECS), and the South China Sea (SCS), are parts of the western North Pacific and rank among the largest marginal seas in the world (Fig. 1). The northern SCS (NSCS) is connected to the YECS through the Taiwan Strait. Both the marginal seas are occupied by wide

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continental shelves with depth shallower than 200 m. Over these seas, the distribution and variability of water properties (e.g., salinity, temperature and density) are strongly influenced by river discharge from mainland China (including the Yangtze River, the Yellow River and the Pearl River), seasonally reversed summer and winter monsoon winds, and the Kuroshio water (KW) that is a major western boundary current in the north Pacific (Chen et al., 1994; Hu et al., 2000; Chen et al., 2006). Although seasonal variation of the KW is comparatively low, great seasonal contrasts of the river runoff (R), precipitation (P) and evaporation (E) caused by the East Asian monsoon climate may produce relatively large seasonal variation of hydrographic structure of these seas. In the last two decades, seawater $\delta^{18}O$ and its relationship with salinity in the YECS and the NSCS have been investigated (e.g., Zhang et al., 1990; Kang et al., 1994; Hong et al., 1994, 1997; Lin, 2000). However, the available data were mostly from a small spatial coverage and very little has been published about the seasonal differences in seawater $\delta^{18}O$. Moreover, there lack comparative studies discussing possible differences in $\delta^{18}O$-salinity relationship between the two marginal sea systems.

In this study, surface water $\delta^{18}O$-SSS relationships inferred from new and extensive measurements of these tracers in the YECS and NSCS are presented. The wide spatial coverage and two season's sampling allowed us to examine the spatial and temporal variations in the associated surface hydrological processes over the YECS and NSCS. Our results may also be helpful for the paleoceanographic studies based on carbonate $\delta^{18}O$ analysis in these marginal seas.

2. Materials and methods

The sampling was conducted in the YECS and the NSCS during two R/V Dongfanghong II expeditions in July–September 2009 and December 2009–February 2010 (Fig. 1). Seawater samples at ~5 m depth were taken using Niskin bottles mounted onto a rosette system. A total of 217 samples, with 92 in summer and 125 in winter, were collected during the two expeditions. All samples were drawn into glass vials, sealed with wax under air temperature and then kept cool until analysis for $\delta^{18}O$. Sea surface temperature (SST) and salinity were recorded using an SBE19-plus conductivity-temperature-depth (CTD) system. The precision was ±0.001 °C for SST and ±0.001 for SSS based on conductivity measurements. Just prior to the cruises, the CTD system was shipped back to Sea-Bird for calibration.

$\delta^{18}O$ analysis was carried out in the laboratory using the standard CO_2–H_2O equilibrium method for $\delta^{18}O$ (Epstein and Mayeda, 1953) in conjunction with a custom headspace auto-sampler connected to an IsoPrime mass spectrometer (GV IsoPrime II). Results were reported in δ-notation ($\delta^{18}O$) relative to the VSMOW in permil (‰). Based on the analysis of random duplicate samples, analytical precision was ±0.08‰ for $\delta^{18}O$. All analyses were performed in the State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, CAS.

3. Results

3.1. Spatial and seasonal distributions

SST and SSS showed clear variations in spatial and seasonal distributions (Fig. 2). Warm waters >24 °C were uniformly distributed across China seas during summer; whereas a nearshore-offshore SST gradient occurred in winter. The SST gradient was small and confined to nearshore area in the low-latitude NSCS, but it became larger and was widely distributed in the YECS. SSS ranged from 25.7 to 33.9 (30.6 ± 2.4 average, $n = 41$)

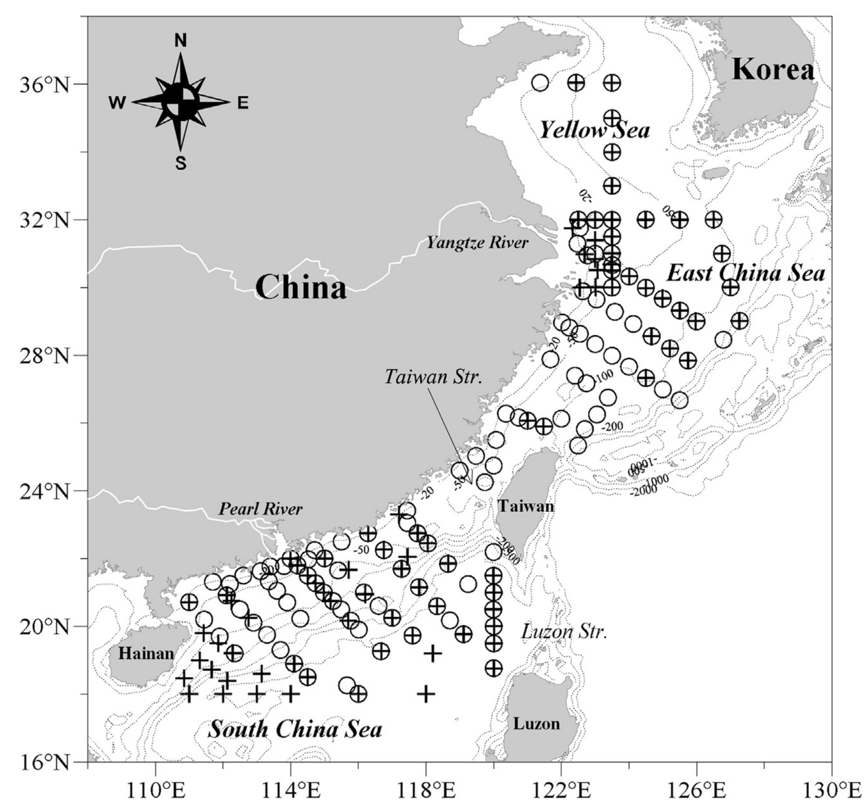

Fig. 1. Map of the marginal China seas showing locations of sampling sites used in this study. Crosses (+) represent sampling sites during summer and open cycles (○) represent sampling stations during winter.