Chlorofluorocarbons indicating the sudden weakening of the thermohaline circulation in the Japan Sea

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In the Japan Sea, there is independent thermohaline circulation: the origin of the deep water is the surface water in the northern Japan Sea because the surface water in winter due to evaporation and freezing is dense enough to sink toward bottom. Therefore, the deep water of the Japan Sea is lower temperature and higher dissolved oxygen than that of the adjacent North Pacific Ocean. The long time-series datasets of water temperature and dissolved oxygen in the deep water of the Japan Sea suggest that the thermohaline circulation in the sea had been weakening due to the global warming in recent decades. The production of chlorofluorocarbons (CFCs: CFC-11, CFC-12 and CFC-113 in this study) began in the 1930s and atmospheric CFCs had increased sharply since the 1960s. CFCs enter the ocean via air-sea gas exchange and do not hydrolyze in seawater. When surface water sinks into deep water by active thermohaline circulation, CFCs concentration of deep water was rewritten by mixing with surface water having high CFCs. Therefore, CFCs of the deep water at present has recorded the information of thermohaline circulation since the 1930s. In June 2011 and October 2012, we obtained vertical CFCs profiles in the eastern Japan Basin and Yamato Basin. The CFCs decreased with depth until above 2200m and then were almost constant at all stations. Therefore, the bottom water was defined as water below 2200m in this study. Although the CFC-11 and CFC-12 of the bottom water in the Yamato Basin were about 1.6 and 1.8 times higher than the Japan Basin, respectively, the CFC-113 was only 1.2 times. Apparent age of the bottom water calculated by CFC-12/CFC-11 ratio showed almost the 1960s regardless of area. If surface water sinking into the bottom water by the thermohaline circulation occurs in a similar scale every winter, the apparent age should show more recent age because atmospheric CFC-11 and CFC-12 had increased sharply since the 1960s. The result suggests that the sinking of surface water had hardly occurred after the 1960s. On the other hand, apparent age of CFC-12/CFC-113 ratio in the bottom water showed almost the 1980s regardless of area. Because CFC-113 has been released in atmosphere since the early 1960s, the result indicates that surface water sinking into the bottom water had occurred even after the early 1970s. These different results may depend on the follows: time history of each CFC in the atmosphere is different and the scale of thermohaline circulation had been changed after the 1970s. We estimate the deep and bottom waters formation rates from 1930 to 2011 at the Japan and Yamato Basins by using simple box model with CFCs. The estimation period is divided into old period from 1930 to 1975 and new period from 1976 to 2011 in consideration of atmospheric CFC-113 time history. The formation rates after 1975 have decreased by 21-30% in the deep water and 15-41% in the bottom water compared with those before 1975. There is no doubt the deep ventilation in the Japan Sea after 1975 has slowed down at least less than half that before 1975. Comparing the effect between the study area, the decrease in formation rate in the Yamato Basin are greater than that in the Japan Basin. These results may suggest that the dynamics of the deep and bottom waters formation, such as the route of deep circulation, had been changed by the sudden weakening of the thermohaline circulation after 1975. This work was supported by Environment Research and Technology Development Fund (ERTDF), the Ministry of the Environment, No. A-1002 “Mechanism elucidation and future forecast on the decreasing trend of dissolved oxygen concentrations in the deep water of the Japan Sea (2010-2012)” and No. 2-1604 “Global warming impacts on thermohaline circulation and subsequent biogeochemical change in the Japan Sea (2016-2018)”.

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