Kuroshio Science **3**-1, 45-48, 2009

Atmospheric Transport of Anthropogenic Pollutants to the Kuroshio Current near Orchid Island, Taiwan

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Abstract

The Kuroshio, which originates east of the Philippines, flows along the east coast of Taiwan and the Japanese archipelago. To understand the impact of anthropogenic pollutants within the Kuroshio Sphere and the role that the Kuroshio plays in the global transport of these compounds, a project was initiated in 2006 by the Kuroshio Research Group, at the Asia-pacific Ocean Research Center, National Sun Yat-sen University. In this ongoing study, concentrations of some of the HOPs, such as PAHs and PCBs in dissolved and particulate phases of the coastal waters, including Kuroshio waters, as well as on overlying air, were analyzed. Estimation of flux of HOPs transported northward by the Kuroshio Current is intended after enough data has been collected. A brief introduction is given in this report with with a focus on the contribution of HOPs originating from Kaohsiung and reaching the Kuroshio Current near Orchid Island via atmospheric transportation.

Key words: absorption, air-water exchange, Kuroshio, PCBs, volatilization

Introduction

For decades, hydrophobic organic pollutants (HOPs) have invaded pristine high latitude areas, moving from developed/developing areas through global oceanic circulation and overlying air. In a recent report, an interesting correlation between PCB, HCH and DDT contamination levels and economic status was found as indicated by the per-capita gross national product (GNP) in those countries influenced by the Kuroshio (Monirith *et al*., 2003). Accordingly, fin line with the prosperous economi growth of those countries, we have observed increasing levels of anthropogenic pollutants to coastal areas and the extent of these contaminants originating from local activities to the Kuoshio waters is of great interest.

The oceans are global reservoirs and ultimate sinks of HOPs (Jurado *et al*., 2004b; Strand and Hov, 1996; Wania *et al*., 1998). These pollutants are mainly transported to the open ocean via atmospheric dry particle deposition, wet deposition and air-water exchange (Jurado *et al*., 2005; Jurado *et al*., 2004a; Li *et al*., 2009; Pandit *et al*., 2006; Poor *et al*., 2004; Tasdemir and Esen, 2007). Among these pathways, air-water exchange is often found to be equally or more important than wet deposition for some HOPs such as PCBs in entering ocean surface water (Bamford *et al*., 2002; Rowe *et al*., 2007; Totten *et al*., 2001; Totten *et al*., 2003). For the Kuroshio Current the dominant anthropogenic sources area the southwestern coastal zone near Orchid Island including Kaohsiung and Tainan City, Kaohsiung, Tso-Ying and Hsing-Ta Harbors as well as several industrial complexes. Among these, Kaohsiung Harbor, the seventh largest harbor in the world, serves as a port for two-thirds of the goods imported to Taiwan. The nearby area surrounding the harbor is Kaohsiung City, the second largest city in Taiwan. The city has a population of 1.5 million and several industrial parks with petrochemical, steel and facilities, as well as “fossil-fuel power plants”.

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Air-borne pollutants originating from these industrial parks and from urban traffic are believed to have a great impact on the waters in the nearby Kuroshio sphere environment.

The flow of the Kuroshio, with a mean speed of 1 m/sec, passes many islets, including Orchid Island and Green Island in the Pacific. The objective of this report is to briefly introduce the multi-year project studying the contribution of HOPs originating from this coastal zone and traveling with the Kuroshio Current near Orchid Island via atmospheric transportation.

1. Methods

The Kuroshiowhich originates east of the Philippines flows along the east coast of Taiwan and the Japanese archipelago (Fig. 1). Serving as a significant source for the

Fig. 1 Sampling sites in Kuroshio sphere
("▲" denotes an air sampling site)

Kuroshio Current near Orchid Island, Kaohsiung Harbor was studied in detail (Fang *et. al*. 2008). Monthly air and water samples were taken concurrently. A high volume air sampler (Graseby Anderson) was used to collected air samples. The sampling apparatus consisted of a polyurethane foam (PUF) and glass fiber filter (Schleicher & Schuell No. 25). Air samples were taken every 24 hours during each sampling event. Water samples were collected in a 20 L polished stainless steel can and shipped to a lab as soon as possible. The collected water samples were pushed by pressurized nitrogen stream (purified by activated carbon) through a 293 mm diameter ashed GFF filter placed inside an aluminum filter holder. The filtered water then passed through a glass column (30 cm × 2.5 cm ϕ) packed with Amberlite XAD-2 resin to retain the dissolved PCBs and HCB in the water samples. After pretreatment, the concentrations of PCB congeners were quantified by an Agilent 4890D gas chromatographer equipped with a ^{63}Ni electron capture detector and a 5% phenyl-methyl silicon capillary column (DB-5, J&W Scientific, 60 m × 0.25 mm × 0.25 μm film) (Fang *et. al*. 2008).

2. Results and Discussion

As shown in Fig. 2, the results from air and surface

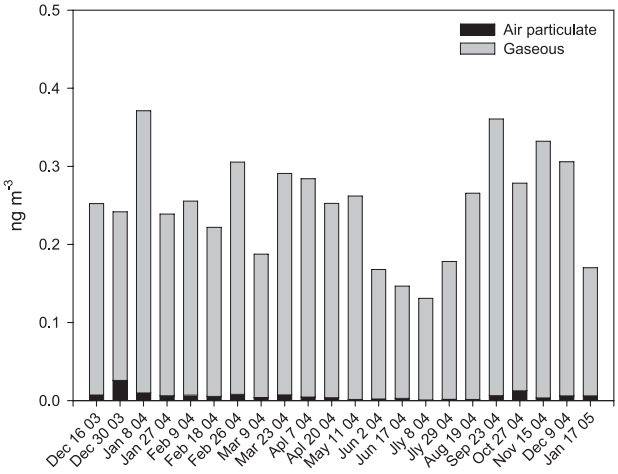

Fig. 2 Total gaseous and particulate PCB concentrations in the atmosphere of Kaohsiung Harbor lagoon from December, 2003 to January, 2005

water samples from Kaohsiung showed that the total PCB (tPCB) concentrations ranged from 0.11 to 0.31 ng m^{-3} for the gas phase and from 0.52 to 1.13 ng L^{-1} for the dissolved phase, with averages of 0.21 ± 0.06 ng m^{-3} and 0.81 ± 0.19 ng L^{-1} respectively (Fang *et al*., 2008). Paired measurements of gaseous and dissolved concentrations, overall mass transfer coefficients, Kol, and magnitudes of fluxes of PCB homologues were measured. K_{ol}s ranged from 0.08 m day-1 for nonachlorobiphenyls in June to 0.36 m day^{-1} for HCB in January. PCB K_{ol} values decreases with increasing molecular weight and the largest K_{ol} values were observed in January when the highest average wind speed was recorded. Throughout the year, the K_{ol} values of PCB homologues and HCB varied in response to wind speed. The daily average wind speeds were higher in winter than in summer, though the values varied greatly throughout our sampling periods. In contrast, water temperatures were lower in winter but higher in summer.

Instantaneous air-water exchange fluxes of the PCB homologues and HCB were calculated from pairs of air and water samples from the Kaohsiung Harbor lagoon. The PCB fluxes were calculated using individual concentrations and temperature-corrected Henry's law constants, and were then summed by homologue group (Bamford *et al*., 2002; Nelson *et al*., 1998). It should be noted that each set of air samples was collected for almost 24 hours, while water samples were collected over a few minutes during the air-sampling period. If the variability of surface water concentrations is significant over a 24-hour period, the gas exchange process might not be adequately explained. All net fluxes of PCB homologues and HCB in this study are from water to air (net volatilization). The highest net volatile flux observed in this study was in December due to the high wind speed and dissolved concentration, while the lowest flux was in January due to the low dissolved concentration. Among the PCB homologue fluxes, the di- to tetra chlorinated homologue fluxes were dominant in the tPCB fluxes, accounting for nearly 80% of the tPCB fluxes (Fig.3).

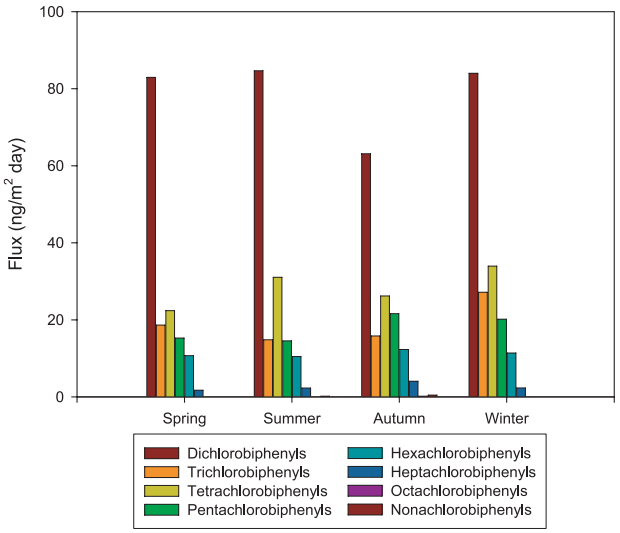

Fig. 3 Seasonal PCB fluxes of (a) di- (b) tri- (c) tetra- (d) penta- (e) hexa- (f) hepta- (g) octa- (h) nonachlorobiphenyls in Kaohsiung Harbor lagoon from December, 2003 to January, 2005

Annual flux of PCBs was calculated by summing up each of the representative daily PCB homologue fluxes which were obtained by temporally extrapolating among the fluxes measured. For example, for the 18 days between January 8 and January 27 when our samples were taken, we assumed the former measurement represented the first 9 days and the latter the other 9 days. The net flux of PCBs suggests that the annual sum of PCBs measured in this study were mainly effluxes from the Kaohsiung Harbor surface water. Parts of the effluxes of these HOPs are believed to make some contribution to the Kuroshio as it moves northward to Japan.

To quantify the annual fluxes of these HOPs into the Kuroshio, a sampling site was set up at the Tabaco campus, of Bicol University, in the Philippines. Only one sample is available so far but seasonal sampling is planned for 2009. This site serves as an upstream sampling spot for the Kuroshio before it arrives along Taiwan's coast. In addition, during 2008, seasonal air sampling campaigns were carried out at four sites, Orchid Island, Keng-ting, KH1(Kaohsiung coast) and KH2 (Kaohsiung urban) (Fig. 1). Additionally, two Kuroshio surface water samples were collected near Orchid Island and analyzed for HOPs. A sampling site in Japan is anticipated for the near future to serve as a downstream sampling spot of the Kuroshio after passes by Taiwan.

Acknowledgements

The authors would like to thank the National Science Council and the Ministry of Education of Taiwan, Republic of China, for financially supporting this work under contract numbers NSC 93-2611-M-110-011, NSC 94-2611-M-110-011 and DOE 95C0302.

References

Bamford, H.A., Ko, F.C. and Baker, J.E. 2002. Seasonal and annual air-water exchange of polychlorinated biphenyls across Baltimore Harbor and the northern Chesapeake Bay. Environmental Science & Technology, 36(20): 4245-4252.

Fang, M. D., Ko, F.-C., Baker, J.E. and Lee, C. L. 2008. Seasonality of diffusive exchange of polychlorinated biphenyls and hexachlorobenzene across the air-sea interface of Kaohsiung Harbor, Taiwan. Science of The Total Environment, 407(1): 548-565.

Jurado, E. *et al*., 2004a. Atmospheric dry deposition of persistent organic pollutants to the Atlantic and inferences for the global oceans. Environmental Science & Technology, 38(21): 5505-5513.

Jurado, E., Lohmann, R., Meijer, S., Jones, K.C. and Dachs, J. 2004b. Latitudinal and seasonal capacity of the surface oceans as a reservoir of polychlorinated biphenyls. Environmental Pollution, 128(1-2): 149-162.

Jurado, E. *et al*. 2005. Wet deposition of persistent organic pollutants to the global oceans.

Environmental Science & Technology, 39(8): 2426-2435.

Li, J., Cheng, H., Zhang, G., Qi, S. and Li, X. 2009. Polycyclic aromatic hydrocarbon (PAH) deposition to and exchange at the air-water interface of Luhu, an urban lake in Guangzhou, China. Environmental Pollution, 157(1): 273-279.

Monirith, I. *et al*. 2003. Asia-Pacific mussel watch: monitoring contamination of persistent organochlorine compounds in coastal waters of Asian countries. Marine Pollution Bulletin, 46(3): 281-300.

Nelson, E.D., McConnell, L.L. and Baker, J.E. 1998. Diffusive exchange of gaseous polycyclic aromatic hydrocarbons and polychlorinated biphenyls across the air-water interlace of the Chesapeake Bay. Environmental Science & Technology, 32(7): 912-919.

Pandit, G.G., Sahu, S.K., Puranik, V. and Raj, V.V. 2006. Exchange of polycyclic aromatic hydrocarbons across the air-water interface at the creek adjoining Mumbai harbour, India. Environment International, 32(2): 259-264.

Poor, N. *et al*. 2004. Atmospheric concentrations and dry deposition rates of polycyclic aromatic hydrocarbons (PAHs) for Tampa Bay, Florida, USA. Atmospheric Environment, 38(35): 6005-6015.

Rowe, A.A., Totten, L.A., Xie, M.G., Fikslin, T.J. and Eisenreich, S.J. 2007. Air-water exchange of polychlorinated biphenyls in the Delaware river. Environmental Science & Technology, 41(4): 1152-1158.

Strand, A. and Hov, H. 1996. A model strategy fro the simulation of chlorinated hydrocarbon distribution in the global environment. Water, Air, and Soil Pollution, 86: 283-316.

Tasdemir, Y. and Esen, F. 2007. Dry deposition fluxes and deposition velocities of PAHs at an urban site in Turkey. Atmospheric Environment, 41(6): 1288-1301.

Totten, L.A. *et al*. 2001. Dynamic air-water exchange of polychlorinated biphenyls in the New York - New Jersey Harbor Estuary. Environmental Science & Technology, 35(19): 3834-3840.

Totten, L.A., Gigliotti, C.L., Offenberg, J.H., Baker, J.E. and Eisenreich, S.J. 2003. Reevaluation of air-water exchange fluxes of PCBs in Green Bay and southern Lake Michigan. Environmental Science & Technology, 37(9): 1739-1743.

Wania, F., Axelman, J. and Broman, D. 1998. A review of processes involved in the exchange of persistent organic pollutants across the air-sea interface. Environmental Pollution, 102(1): 3-23.