3D3) Measurements of Atmospheric Gaseous Elemental Mercury over the Yellow Sea during 2007-2008

Duc Luong Nguyen[1),2)], Jin Young Kim[1)], Shang Gyoo Shim[1)], Hyoun Cher Jin[1)], Xiao-shan Zhang[3)]

[1)]Center for Environmental Technology Research, Korea Institute of Science and Technology, [2)]University of Science and Technology, [3)]Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences

1. Introduction

The Yellow Sea is directly connected to the eastern coast of China which is one of the largest anthropogenic mercury emission areas in China. At present, China is the largest single country polluter regarding to mercury which contributes approximately 30% of the global mercury emissions. Due to the dominance of westerly wind in all seasons except summer, the Yellow Sea is readily suffered from long-range transport of atmospheric gaseous elemental mercury (Hg^0) which is emitted from highly polluted areas in China. The objectives of this study were to improve our knowledge on the atmospheric Hg^0 concentration over the Yellow Sea and identify the source regions of long-range transported Hg^0 measured at background site in Korea.

2. Methods

Measurements of Hg^0 concentration were conducted at two background sites including Chengshantou (a coastal site in Weihai, East China), Deokjeok (an island in Korea), two urban sites including Beijing and Ningbo (both in China), and along three routes over the Yellow Sea (Incheon to Jeju, Korea; Incheon to Qingdao, China; and Incheon to Weihai, China) during different periods from June 2007 to August 2008 as shown in Fig. 1. Ground-based and shipboard measurements were both made using RA-915$^+$ mercury analyzer.

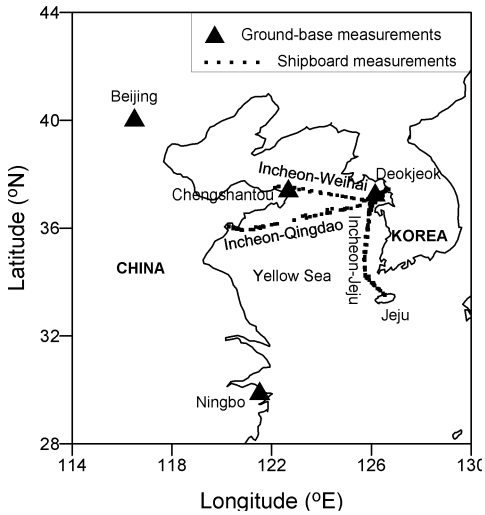

Fig. 1. A map of sampling sites in Korea, China and three moving routes of ship over the Yellow Sea: Incheon-Jeju; Incheon-Qingdao; and Incheon-Weihai.

3. Results and Discussion

3.1 Hg^0 background concentration over the Yellow Sea

Hg^0 mean concentrations measured at sampling sites and over the Yellow Sea for the entire study period in 2007 - 2008 were depicted in Fig. 2a. In considering the background sites, Hg^0 mean concentration acquired at Chengshantou (2.23±0.91ng m^{-3}) was relatively higher than that at Deokjeok (1.79±0.80ng m^{-3}). In comparison with Hg^0 mean concentration of 1.15±0.59ng m^{-3} observed at Mt. Waliguan, a remote continental background area of China (Wang et al., 2007), value measured at Chengshantou was also significantly higher. Compared to Hg0 mean concentrations measured at two urban sites in China, Beijing (5.19±3.55ng m^{-3}) and Ningbo (4.16±1.79ng m^{-3}), those measured at two background sites were significantly lower. Highly elevated Hg^0 concentrations along with their large variabilities observed at Chinese urban sites are evidences for the strong impact from variety of local anthropogenic mercury sources.

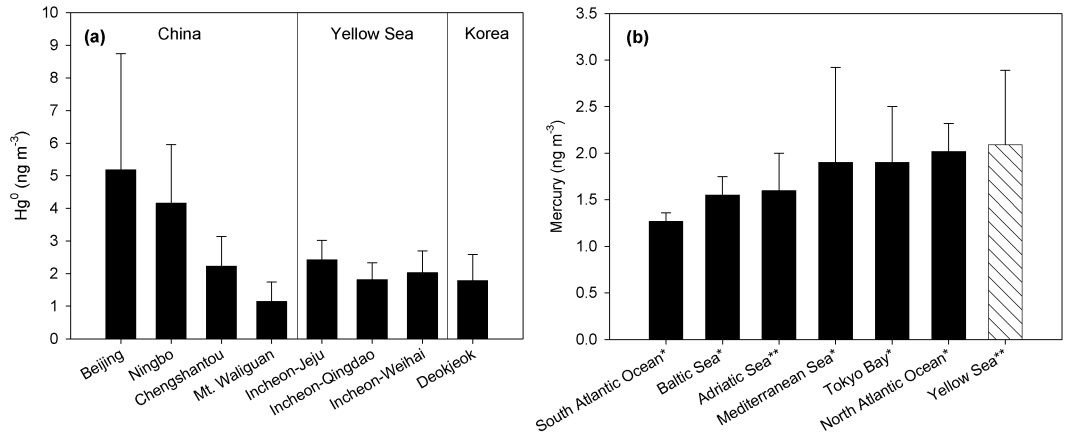

Fig. 2. (a). Hg^0 mean concentrations measured at sampling sites and over the Yellow Sea during the study periods in 2007 - 2008; (b). Comparison of mercury concentrations measured over other seas/oceans around the world and the Yellow Sea: (*) and (**) denote for total gaseous mercury (TGM) and Hg^0, respectively. TGM typically includes two mercury species: Hg^0 (the most predominant, constitutes 98% or more of TGM) and reactive gaseous mercury (<1% of TGM). Whiskers above the bars indicate the standard deviations.

Hg^0 mean concentrations observed over the Yellow Sea were 2.43±0.59, 1.82±0.51, and 2.03±0.66ng m^{-3} for the routes of Incheon-Jeju, Incheon-Qingdao, and Incheon-Weihai, respectively. Hg^0 mean concentration measured along the route of Incheon-Jeju emerged to be noticeably higher than those found along the other routes possibly due to the impact of local mercury sources from inland Korea since the ship was moving along the coastal line during the sampling period. Based on the measured results along three routes, the Hg^0 background concentration over the Yellow Sea was suggested to be 2.09±0.80ng m^{-3}. In comparison with the Hg^0 background concentrations reported for other seas/oceans around the world (Wängberg et al., 2001; Sprovieri et al., 2003; Temme et al., 2003; Narukawa et al., 2005; Sprovieri and Pirrone, 2008), the value over the Yellow Sea was generally higher (Fig. 2b). Since westerly wind usually dominate over the East Asia, mercury emitted from populated and industrialized areas in Chinese eastern coast would be transported to the east or sometimes mercury emitted from inland sources in Korea might be transported to the west under the

influence of easterly wind. In consequence, the Hg^0 background concentration over the Yellow Sea is expected to be higher than those over other seas/oceans worldwide.

3.2 Long-range transport episodes measured at Deokjeok Island in Korea

During the spring sampling periods in 2008, Hg^0 hourly mean concentrations obtained at Deokjeok site were undergoing considerable enhancement several times in comparison with the Hg^0 background concentration over the Yellow Sea as shown in Fig. 3a. There were two spring episodes of highly elevated Hg^0 concentrations. Backward trajectory analysis (Fig. 3b) pointed out that air masses arrived at the Deokjeok site during the 1st episode (numbered 1) and the 2nd episode (numbered 2) were originated from different directions, however, both passed over the southern part of Liaoning province, northeastern China. Due to the presence of two major sources which non-ferrous metals smelting and coal combustion (Streets et al., 2005; Wu et al., 2006), Liaoning province has been regarded as one of the heaviest mercury-polluted areas in China, which is ranked the first and fifth highest in 1999 and 2003, respectively in terms of Chinese provincial level for mercury emissions. Thus it is plausible that air masses when passing over Liaoning province might carry certain amount of mercury from this region to Deokjeok and resulted in enhanced Hg^0 concentrations. With respect to the summer period, air masses arriving at Deokjeok site (numbered 3) usually originated from the East Sea which are typically clean marine background air masses, is considered as the main cause for the low Hg^0 concentrations.

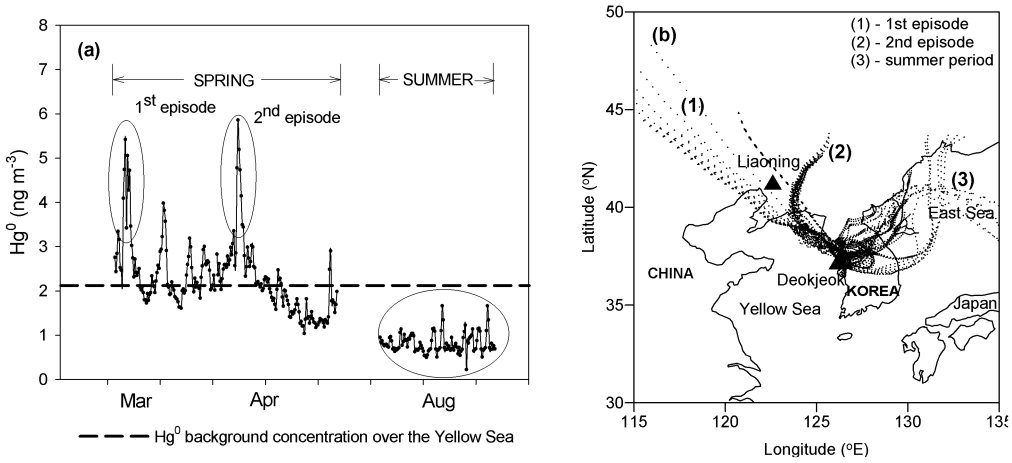

Fig. 3. (a). Hg^0 hourly mean concentrations measured at Deokjeok Island during the study periods in 2008: 1st episode - from 09 pm 17 Mar to 06 am 18 Mar and 2nd episode - from 08 am to 03 pm 12 Apr; (b). NOAA-HYSPLIT three-day backward trajectories arrived at Deokjeok Island during different study periods in 2008.

4. Summary

This study shows that the Hg^0 background concentration over the Yellow Sea was generally higher than those observed over other seas/oceans around the world. Hg^0 concentrations measured in the urban atmosphere were significantly higher than the background concentration in China. Elevated Hg^0 concentrations at Deokjeok Island in Korea were attributed to long-range transport of mercury from high emission areas in China.

References

Narukawa, M., M. Sakata, K. Marumoto, and K. Asakura (2006) Air-Sea Exchange of Mercury in Tokyo Bay. Journal of Oceanography, 62, 249-257.

Sprovieri, F. and N. Pirrone (2008) Spatial and temporal distribution of atmospheric mercury species over the Adriatic Sea. Environ Fluid Mech, 8, 117-128.

Sprovieri, F. N., Pirrone, K. Gårdfeldt, and J. Sommar (2003) Mercury speciation in the marine boundary layer along a 6000km cruise path around the Mediterranean Sea. Atmospheric Environment 37, Supplement No. 1, 63-71.

Streets, D.G., J. Hao, Y. Wu, J. Jiang, M. Chan, H. Tian, and X. Feng (2005) Anthropogenic mercury emissions in China. Atmospheric Environment, 39, 7789-7806.

Temme, C., F. Slemr, R. Ebinghaus, and J.W. Einax (2003) Distribution of mercury over the Atlantic Ocean in 1996 and 1999-2001. Atmospheric Environment 37, 1889-1897.

Wang, Z.W., Z.S. Chen, N. Duan, and X.S. Zhang (2007) Gaseous elemental mercury concentration in atmosphere at urban and remote sites in China. Journal of Environmental Sciences-China, 19, 176-180.

Wängberg, I., S. Schmolke, P. Schager, J. Munthe, R. Ebinghaus, and A. Iverfeldt 2001. Estimates of air-sea exchange of mercury in the Baltic Sea. Atmospheric Environment, 35, 5477-5484.

Wu, Y., S. Wang, D.G. Streets, J. Hao, M. Chan, and J. Jiang (2006) Trends in Anthropogenic Mercury Emissions in China from 1995 to 2003. Environ. Sci. Technol., 40, 5312-5318.