Impact to ambient ozone concentration by ship emission regulation in Seto Inland Sea

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Abstract –**The Annex VI on "Regulations for the Prevention of Air Pollution from Ships" in MARPOL 73/78 was revised to progressively reduce air pollutant emissions. The revised Annex VI will go into effect in July 2010. This study estimated changes in air pollutant emissions from ship after the effect of the revised Annex VI and impact of the change in emission on air quality. For the estimate of change in ship emission from the present to 2050 in Japan, following assumptions were applied: the life of ship is 30 years; net increase rate of shipping tonnage is 2.3%/year; the ratio of dismantled ships against total shipping tonnage is 2.2%/year; new ships are constructed by 4.5%/year. The total amounts of NO_X and SO_X emission in the study region in and around the Seto Inland Sea are expected to be decreased by 15.7% and 27.8% between the present and 2050, respectively. The MM5/CMAQ modeling system was utilized to predict the impact of the ship emission regulation on air quality around the Seto Inland Sea. The average NO_2 and aerosol SO_4^{2-} concentrations were decreased by up to 13ppb and 2.0 μg/m^3 in land area, respectively. The average O_3 concentration at 15h were decreased by up to 2.3ppb (mean = 0.5ppb) with only the ship emission regulation and by up to 4.8 ppb (mean = 1.6ppb) with both the ship emission regulation and additional VOCs reduction in land areas. The results shows that combination of ship emission regulation and land base VOCs regulation is more effective for the decreases of air pollutant concentrations in larger area.**

I. INTRODUCTION

Emissions containing nitrogen oxides (NO_X) and sulphur oxides (SO_X) generate secondary pollutants such as ozone (O_3) and particulate matter. International shipping has grown over the past half-century, which has resulted in a significant increase of Air pollutant emissions from ship [1]. On the other hand, land-based air pollutant emissions are decreasing due to several environmental regulations. Therefore ship emission will form a significant portion of regional emission and cannot be neglected in assessing the impacts of air pollution in the future.

The International Maritime Organisation (IMO) adopted the Annex VI on "Regulations for the Prevention of Air Pollution from Ships" in the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) in September 1997. The Annex VI has been revised to progressively reduce air pollutant emissions from ship. The revised Annex VI will go into effect in July 2010 [2].

This study evaluated the impact of the ship emission regulation based on the revised Annex VI on air quality around Seto Inland Sea in Japan. First, change in ship emission was estimated for from the present to 2050 in Japan. Second, the 5th generation Penn State University/ National Center for Atmospheric Research Mesoscale Model (MM5) [3] and the U.S. Environmental Protection Agency's Models-3 Community Multiscale Air Quality (CMAQ) [4] modeling system was utilized with the estimated emission data to predict changes in air quality between in 2008 and in 2050.

II. MODEL STRUCTURE

The models used in the present study include MM5 version 3.7 and CMAQ version 4.7. MM5 is a three-dimensional, nonhydrostatic, terrain-following sigma-pressure coordinate model with a multiple-nest capability, several physics options, and a four-dimensional data assimilation capability. The model is widely used to drive air quality models. CMAQ is a three-dimensional Eulerian air quality modeling system that simulates the transport, transformation, and deposition of various air pollutants and their precursors across spatial scales ranging from local to hemispheric.

Fig. 1 shows modeling domains for CMAQ prediction. The study region is centered at (122.5°E, 32.0°N) on the Lambert conformal conic projection map of East Asia. The horizontal domains consist of 3 domains from domain 1 (D1) covering a wide area of East Asia to domain 3 (D3) covering the Kinki Region of Japan. The horizontal resolutions and the number of grid cells in the domains are 54, 18 and 6 km, and 105 × 81, 72 × 72 and 72 × 72 for D1, domain 2 (D2) and D3, respectively. The vertical layers consist of 24 sigma-pressure coordinated layers from the surface to 100 hPa with approximately 15m as the middle height of the first layer.

For meteorological prediction, MM5 was configured with the scheme of Grell et al. (1994) for the cumulus parameterization, the medium range forecast scheme [5] for the planetary boundary layer parameterization, the schemes of Dudhia [6] for the cloud microphysics and the radiation simulations, and the scheme of Dudhia [7] for the land surface interactions . The input data for MM5 include the National Centers for Environmental Prediction final analysis (NCEP FNL) data, and the grid point value derived from the mesoscale model (GPV MSM) data by JMA. The NCEP FNL data are global analysis data with a spatial resolution of 1° × 1° and a temporal resolution of 6 h. The GPV MSM data are available for the Japan region

and have a high spatial resolution of 0.125° (for longitude) × 0.1° (for latitude) and a temporal resolution of 3 h. Initial and boundary conditions for MM5 were obtained from the NCEP FNL for D1, and the GPV MSM for D2. Boundary conditions for D3 were updated every hour from the MM5 output files for D2. MM5 was run for July 2008 with an initial spin-up period of 6days (25-31 June 2008). The MM5 hourly results were processed using the Meteorology-Chemistry Interface Processor (MCIP) version 3.4 for CMAQ predictions.

For chemical prediction, CMAQ was configured with the Statewide Air Pollution Research Center version 99 (SAPRC99) [8] mechanism for the gas-phase chemistry, the 5th generation CMAQ aerosol module (AERO5) for the aerosol processes, and the cloud and aqueous phase chemistry option. Initial and boundary conditions for D1 were obtained from the CMAQ default concentration profiles. Boundary conditions for D2 and D3 were updated every hour from the CMAQ hourly results of D1 and D2, respectively.

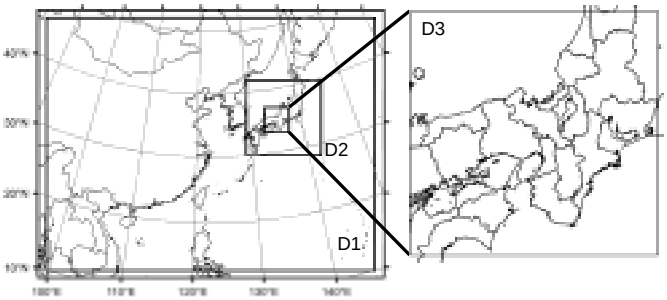

Fig. 1. Modeling domains for CMAQ prediction

III. STANDARD EMISSION DATA

Emission data applied in this study include anthropogenic, biogenic VOCs (BVOCs), biomass burning and volcanic SO_2 emissions. Anthropogenic and BVOCs emissions for the Japan region were derived from EAGrid2000-Japan [9]. EAGrid2000-Japan is an emissions inventory for Japan with a high spatial resolution of 45″ (for longitude) × 30″ (for latitude) and a temporal resolution of 1 h for weekdays and holidays in every month of 2000. For the other Asian countries, anthropogenic emissions of SO_2, NO_X, CO, VOCs and PM were obtained from an emissions inventory for Asia in the year 2006 with a 0.5° × 0.5° spatial resolution developed to support the Intercontinental Chemical Transport Experiment-Phase B (INTEX-B) [10]. Emissions of NH_3 were derived from predicted values for the year 2005 in regional emission inventory in Asia (REAS) with a 0.5° × 0.5° spatial resolution [11]. BVOCs and biomass burning emissions were derived from Murano [12] and Streets et al [13], with 0.5° × 0.5° and 1° × 1° spatial resolutions, respectively. In addition, sea salt emissions were calculated within the AERO5 module as a function of wind speed and relative humidity, following the parameterizations of Gong [14] and Zhang et al [15] , respectively .

The regulation scenario of air pollutant emissions was applied to EAGrid2000-JAPAN.

IV. SCENARIO

For the regulation scenario of ship emission, three assumptions had to be applied on the basis of the IMO regulation. Fig.2 and 3 shows the limit to NO_X and sulpher content according to IMO regulations. The IMO regulations for NO_X and sulphur will be implemented as planned. First, it is assumed that the marine waters around Japan will be designated an Emission Control Area (ECA) as defined by IMO. ECA requires severe NO_X and SO_X emission restrictions for new ships from 2016. Second, concerning the amount of ship traffic, an annual increase of 2.3% has been assumed for transport of goods from 2008 according to Ocean Policy Research Foundation (OPRF) [16] prediction from Intergovernmental Panel on Climate Change(IPCC) A1B scenario [17]. Third, the age of vessel is 30 years old. Fig.4 shows transitions of ship emissions from 2000 to 2050, (The proportion in 2000 is 100). NO_X emission will increase gradually until 2016 and decrease gradually afterward. SO_X emission will increase until 2016 and decrease dramatically in 2016 because of the introduction of ECA and gradually increase afterward.

The year of 2008 was taken as a baseline emission case (2008_present), while the study considered a case: with ship regulation (2050_A1B). In both cases, CMAQ was driven with the meteorology field for July 2008.

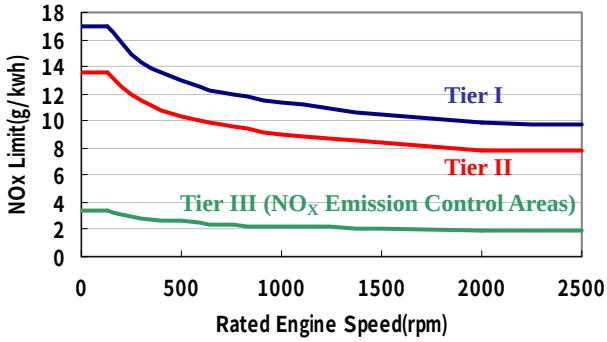

Fig. 2. Limit to NO_X emission from ship according to IMO regulations

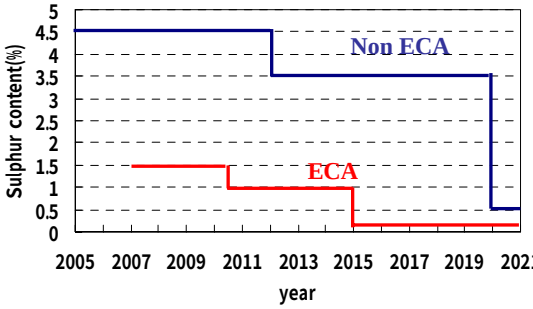

Fig. 3. Limit to sulpher content in ship fuel oil, according to IMO regulations

Fig.5 shows emissions in D3 in 2008 and 2050. The total amounts of NO_X and SO_X emission in D3 are expected to be decreased by 15.7% and 27.8% between 2008 and 2050, respectively.

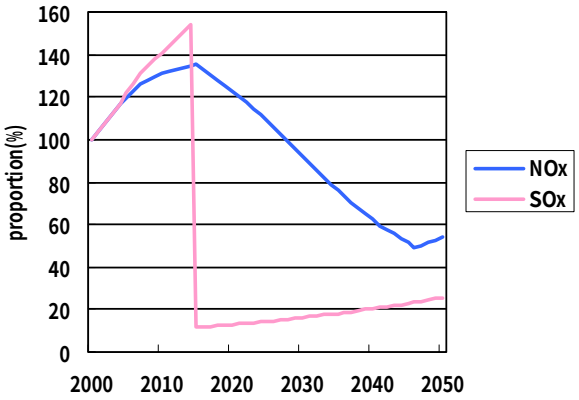

Fig. 4. Transitions of ship emissions from 2000 to 2050 (The proportion in 2000 is 100)

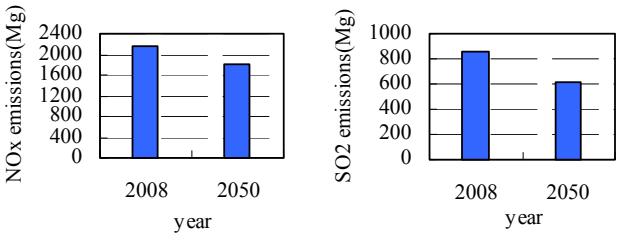

Fig. 5. Emissions in D3 in 2008 and 2050

V. RESULT AND DISCUSSION

A. NO_2 and Aerosol SO_4^{2-} Concentrations

Fig.6a and b show spatial distribution of average NO_2 concentrations in 2008_present, and the concentrations differences between in 2050_A1B and in 2008_present in D3, respectively. In 2008, high concentrations of NO_2 were at locations adjacent to the port where the operations of ship's engines emitted high amounts of NO_X (Fig.6a). On the other hand, in 2050 the decrease in the average concentrations of NO_2 was up to 13ppb in the coastal area (Fig.6b). Fig.7a and b show spatial distribution of average aerosol SO_4^{2-} concentrations in 2008_present, and the concentrations differences between in 2050_A1B and in 2008_present in D3, respectively. In 2008 High concentrations of aerosol SO_4^{2-} were at locations adjacent to the port where the operations of ship's engines emitted high amounts of SO_X (Fig.7a). On the other hand, In 2050 the decrease in the average concentrations of aerosol SO_4^{2-} was up to 2.0μg/m^3 in the coastal area (Fig.7b). The results indicate the regulation of ship emission can significantly contribute to the decrease of the concentrations of NO_2 and aerosol SO_4^{2-} in the coastal area.

B. O_3 Concentrations

The photochemical O_3 formation process is complex, because many kinds of VOCs are involved with the process [18]. Aromatics, such as toluene and xylene, and olefins, such as butene and hexene, tend to significantly contribute to photochemical O_3 formation [19]. Therefore regulation of these compounds in land area was assumed in addition to the regulation of ship emission. The emission of these compounds from evaporative VOCs sources, including paint application, printing, fugitive fuel and other stationary evaporative was set to be 0. As a result, the total amount of anthropogenic VOCs emission in D3 was decreased by 26.7% (583Mg/y). Following four cases were considered : 2008_present, 2008_presrnt with VOCs regulation (2008_VOCreg), 2050_A1B, 2050_A1B with VOCs regulation (2050_A1B_VOCreg).

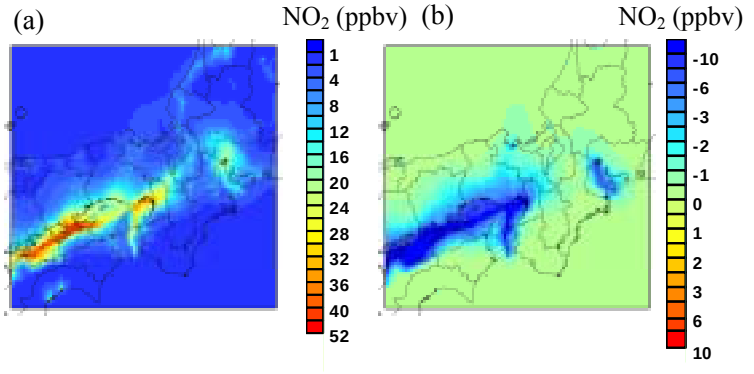

Fig. 6. Spatial distributions of (a) NO_2 concentration in 2008_present and (b) NO_2 concentration difference between in 2050_A1B and in 2008_present in D3.

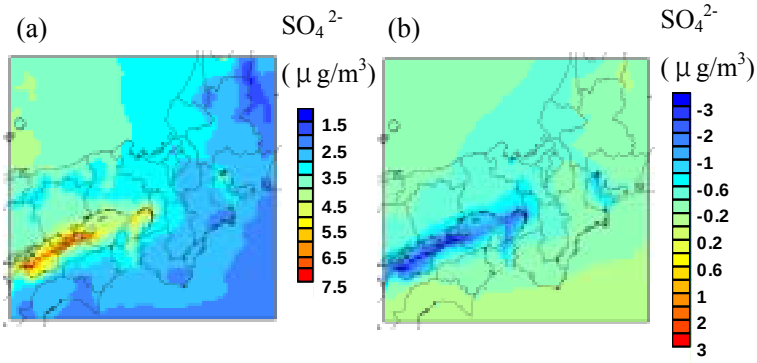

Fig. 7. Spatial distributions of (a) aerosol SO_4^{2-} concentration in 2008_present and (b) aerosol SO_4^{2-} concentration difference between in 2050_A1B and in 2008_present in D3.

Fig.8a, b, c and d show spatial distribution of the average O_3 concentrations at 15h in 2008_present, the concentrations differences between in 2008_VOCreg and in 2008_present, between in 2050_A1B and in 2008_present and between in 2050_A1B_VOCreg and in 2008_present in D3. In 2050_A1B, the O_3 concentration was considerably increased in the Seto Inland Sea and along the coast due to the decrease in NO that contributes to O_3 destruction. The maximum decrease of 2.3ppb (mean = 0.5ppb) was in land area due to the decrease of the transport of NO_2 that contributes to O_3 production. Therefore it shows that ship emission regulation influences O_3 concentrations decrease at some distance from the coast (Fig.8c). In 2050_A1B_VOCreg, the maximum decrease was 4.8ppb (mean = 1.6ppb) in land area (Fig.8d). Compared to 2008_VOCreg (mean =1.2ppb), O_3 concentrations decreased in larger area. It shows that ship emission regulation with VOC reduction has more impact on the decrease of O_3 concentrations in larger area than only ship emission regulation. 24-h average O_3 concentrations indicate a similar tendency.

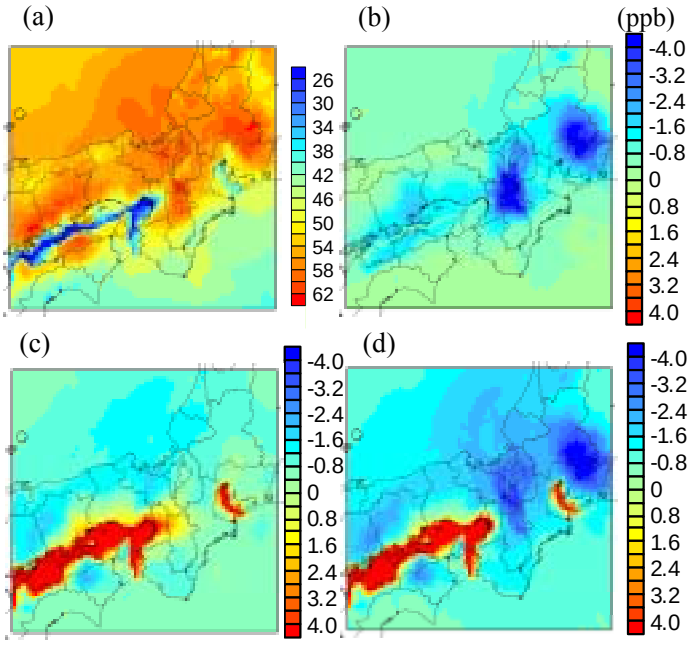

Fig. 8. Spatial distributions of average O_3 concentrations at 15h. (a) O_3 concentrations in 2008_present, (b) the concentration differences between in 2008_VOCreg and in 2008_present, (c) between in 2050_A1B and in 2008_present and (d) between in 2050_A1B_VOCreg and in 2008 _present in D3

VI. CONCLUSION

This study evaluated the impact of ship emission regulation to air pollutant concentrations around Seto Inland Sea using MM5/CMAQ model. Air pollutant emissions from ship in 2050 were estimated. This study showed that the maximum model-predicted decreases by ship emission regulation were respectively 13 ppb and 2.0μg/m^3 for NO_2 and aerosol SO_4^{2-} along the coast. The average O_3 concentrations at 15h decreased by up to 4.8ppb (mean = 1.6ppb) with ship emission regulation and VOC reduction and 2.3 ppb (mean = 0.5ppb) with only ship emission regulation in land area. The results show that ship emission regulation is more effective for the decrease of O_3 concentrations in larger area by combination of land base VOC reduction.

VII. REFERENCES

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