



Influence of ship emission on atmospheric pollutant concentration around Osaka Bay, Japan

A. Kondo⁽¹⁾, K. Yamaguchi⁽¹⁾, E. Nishikawa⁽²⁾

*⁽¹⁾Dep. of Environmental Eng., Osaka University, Yamada-oka
2-1 Suita Osaka, Japan*

*⁽²⁾Dep. of Engineering, Kobe University of Mercantile Marine,
Fukae-minami 5-1-1, Higashinada, Kobe, Japan
Email: e-nskw@cc.kshosen.ac.jp*

Abstract

Marine traffic in Osaka Bay is very intensified and much atmospheric pollutant (SO_x and NO_x) from ships is released but there is no regulation about the ship emission. In this paper, we investigated the emission amounts of SO_x , NO_x and HC from car, factory and ships in Osaka bay area and estimated the influence of the ship emission on the atmospheric pollutant concentration, using both the meteorological prediction model and the atmospheric pollutant concentration prediction model including the dry deposition and the chemical reaction. In Osaka bay area, the emission amounts of SO_x and NO_x from ships were about 30 % of the total emission amounts, respectively. Using these emission data, the atmospheric pollutant concentration was simulated on a summer fine day when high oxidant concentration was measured at several observatories and was compared with the observed data. Though some differences were seen between the simulated results and the observed data, the diurnal variation agreed reasonably. The second simulation was carried out except for the ship emission and we estimated the influence of the ship emission on the atmospheric pollutant concentration. It was found that the ship emission raised SO_2 , NO_2 and NO concentration not only in shore area but also in 40km inland.

1 Introduction.

The emission amount of the atmospheric pollutant increases very much

in the city because of the concentration of the industry and the population. Although SO_2 concentration has been decreasing by the emission regulation of factory in Japan, it is hard to say that good air environment is preserved about the oxidant concentration, NO_2 concentration, and SPM. Under such a situation, "the automobile NO_x regulation law" was proclaimed in 1992 in Japan. Thus, although various regulations are carried out about the emission from factory and car, the regulation about the ship emission is not performed internationally not only in Japan at all. It is considered that the rate of the emission amount from ship is increasing relatively because the emission regulations of factory and car is performed. It is important to evaluate the influence that the ship emission has affected atmospheric pollutant concentration, when the emission regulation from ship will be carried out from now on. Then, we examined the influence that the emission amount from ships in Osaka Bay affects atmospheric pollutant concentrations, using the numerical model.

2 Atmospheric pollutant concentration prediction model.

Both the meteorological prediction model¹ and the atmospheric pollutant concentration prediction model were used to predict the atmospheric pollutant concentration.

2.1 Conservation equation for the concentration.

The conservation equation for the concentration is expressed with Eqn.(1) using z^* coordinate system.

$$\begin{aligned} \frac{\partial c_i}{\partial t} = & -u \frac{\partial c_i}{\partial x} - v \frac{\partial c_i}{\partial y} - w^* \frac{\partial c_i}{\partial z^*} + \frac{\partial}{\partial x} (K_H^{(c)} \frac{\partial c_i}{\partial x}) + \frac{\partial}{\partial y} (K_H^{(c)} \frac{\partial c_i}{\partial y}) \\ & + \left(\frac{s}{s - z_G} \right)^2 \frac{\partial}{\partial z^*} (K_V^{(c)} \frac{\partial c_i}{\partial z^*}) + R_i + Q_i \end{aligned} \quad (1)$$

where c is the atmospheric pollutant concentration, u, v and w^* are the wind speed in the direction of x, y and z^* , $K_H^{(c)}$ and $K_V^{(c)}$ are the horizontal and the vertical turbulent diffusion coefficient, R is the source/sink due to the chemical reactions, Q is the point source, and the suffix i is the chemical species. s is the calculated region height and z_G is the terrain height. The horizontal turbulent diffusion term in Eqn.(1) was omitted, since the numerical diffusion by the horizontal advection is assumed to be much larger than the horizontal turbulent diffusion. The vertical turbulent diffusion coefficient was determined using the turbulence closure Level 2.5 model². We used the new positive definite advection scheme proposed by Smolarkiewicz³ for the advection term, and the central difference for the diffusion term.

2.2 Dry deposition.

The deposition resistance is made up of a series of the aerodynamic resistance, the viscous resistance, and the surface resistance, and the deposition

velocity v_g is expressed with Eqn.(2).

$$v_g = \frac{1}{r_t} = \frac{1}{r_a + r_b + r_c} \quad (2)$$

where r_t is the total resistance, and r_a , r_b , and r_c are the aerodynamic resistance, the viscous resistance, and the surface resistance, respectively. As it is difficult to formulize the surface resistance to change with the states of the ground surface, we simply classified the ground surface into three categories of the artificial surface (concrete and asphalt), the soil surface, and the water surface, and gave each surface resistance value from literature.

2.3 Chemical reaction.

We used CBM-IV developed by Gery⁴ as the photo chemical reaction model. The CBM-IV mechanism includes 32 species and 81 reactions; photochemical, inorganic, and organic reactions.

3 Calculation conditions.

3.1 Calculated region.

The horizontal calculated region is 166km in the east - west directions and 206km in the north - south direction shown in Fig.1 and is divided into 30 x 30 meshes. The vertical calculated region is 5000m height, and is divided into 14 layers, of which the grid interval is set to 8, 8, 8, 8, 48, 129, 210, 290, 371, 452, 532, 613, 694, 774 and 855m from the lower layer, respectively. The calculated results of the wind velocity, the wind direction and NO, NO₂, O₃, and SO₂ concentration are compared with the observed data at the observatories A~F in Fig.1.

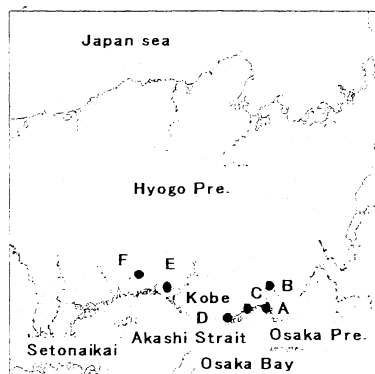


Figure 1 The calculated region.
Six observatories are located at points A~E.

3.2 Calculated period.

The calculated period is 72 hours from 10:00 on August 2, 1990. In this period, the Pacific Ocean high pressure had covered Japan, and the fine day continued. Moreover the oxidant concentration recorded the high value exceeded 120 ppb at several observatories.

3.3 Initial conditions and boundary conditions of flow field.

The initial value of the wind velocity was given 0 in all domains. The initial value of the potential temperature was given 298K on the ground surface, and the constant potential temperature gradient 0.005K/m in all

Table 1: Initial concentrations [ppb].

Species	0[m] ~ 209[m]	209[m] ~
NO	15	2
NO ₂	15	2
O ₃	20	20
SO ₂	10	10

domains. Moreover, the initial values of the turbulent variables were determined from the turbulent closure Level 2 model.

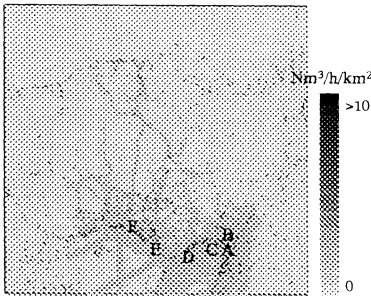
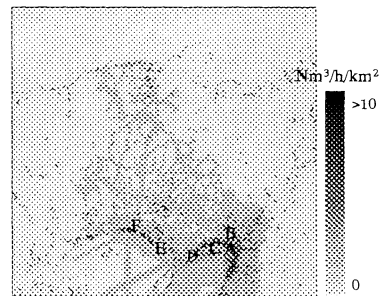
The surface temperature and the specific humidity were determined solving the ground surface heat budget equation. The potential temperature and the wind velocity of the bottom boundary were determined from the similarity theory of Monin-Obukhov. The lateral boundary conditions were set to the gradient = 0 to all variables.

3.4 Initial conditions and Boundary conditions of concentration field.

The initial concentration values of the main species were shown in Table 1. It was assumed that the concentration value on the upper boundary did not change during the calculation period, and the lateral boundary conditions were set to the gradient = 0. The bottom boundary conditions were given by flux F in Eqn. (3).

$$F = -v_g \cdot c + Q_{sf} \quad (3)$$

where Q_{sf} is the emission flux from the ground surface.


Figure 2 SO_x emission map.

Figure 3 NO_x emission map.

3.5 Calculation procedure.

If performing the flow and the concentration calculation simultaneously, much calculation time is needed. Therefore, the calculation of the flow field was performed beforehand and saved the data required at the concentration calculation in every hour into the hard disk.

4 Estimation of the emission amount.

Table 2: Emission amount of SO_x and NO_x .

Source	SO_x	Ratio	NO_x	Ratio
	[ton/year]	[%]	[ton/year]	[%]
(1)Factory	33,904	59.2	58,690	33.7
(2)Car	4,664	8.1	57,053	32.8
(3)Ships	18,609	32.5	56,480	32.5
(4)Airplane	70	0.1	1,792	1.0
Total	57,247	100.0	174,015	100.0

Table 3: Emission amount of anthropogenic HC.

Source	Emission	Ratio
	[ton/year]	[%]
(1)Store	1822	0.9
(2)Shipment	3628	1.9
(3)Gasoline Vapor	11931	6.1
(4)Manufacturing	8516	4.4
(5)Painting	60150	30.9
(6)Construction painting	35399	18.2
(7)Printing	24325	12.5
(8)Surface processing	6659	3.4
(9)Cleaning	10859	5.6
(10)Solvent	3232	1.7
(11)Combusion	1651	0.8
(12)Car	26541	13.6
Total	194717	100.0

We estimated the emission amount of SO_x , NO_x , and HC in Hyogo and Osaka prefecture, and Osaka bay to the purpose which investigated the emission contribution from ships. The emission amount of other domain was assumed to be 0.

4.1 Estimation of SO_x and NO_x emission.

The sources of SO_x and NO_x emission were classified into 4 categories (1) factory, (2) car, (3) ships, and (4) airplane. The estimated emission amount of SO_x and NO_x was shown in Table 2. Moreover, the emission amount maps were shown in Fig.2 and Fig.3. The emission amount of SO_x and NO_x from ships were 18609 [ton/year] and 56480 [ton/year], respectively. The total number of the ships in Osaka bay is about 400,000 [year^{-1}]. The number of the ferries with the large emission coefficient occupies about 230,000 [year^{-1}] among them. Furthermore, the number of the ships which pass through the Setonaikai is 60,000 [year^{-1}]. For these reasons, the emission amount from ships occupies about 30% of the total emission amount around Osaka bay area.

Table 4 Condition of ship emission.

Stack height [m]	Amount of exhaust gas [Nm ³ /hour]	Tem. of exhaust gas [°C]
10	348	300
20	1025	300
30	2966	300

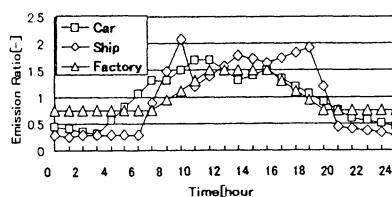


Figure 4 Diurnal variations of emission rate.

4.2 Estimation of HC emission.

Classified into the anthropogenic sources (12 categories) and the natural sources, the emission amount of HC was estimated. The estimated emission amount of HC was shown in Table 3. Four sources of (5)painting, (6)construction painting, (12)car, and (7)printing were about 75% of the anthropogenic total emission amounts. The natural sources are the forest and the rice field. The emission amount of HC from the natural source was 167,000 [ton/year] in only Hyogo prefecture and was almost as same as that from the anthropogenic sources.

4.3 Effective stack height.

The emission from factory and ships was treated as the point source (Q in Eqn.(1)). The effective stack height was computed from CONCAWE formula and from the weighted average of Briggs and CONCAWE formula at the calm. On the basis of data of the Akashi strait passage ship, the stack height and the amount of exhaust gas of the ships were classified into three categories (Table 4).

4.4 Diurnal variations of the emission amount.

The diurnal variations of the emission amount from car, factory, and ships (berth) were shown in Fig.4. The emission amount of from ships (route) was assumed to be constant. The vertical axis in Fig.4 is the ratio to the mean emission amount.

5 Comparison with observation data.

5.1 Comparison of flow field.

The diurnal variations of the observed and the calculated wind vectors at six observatories in Fig.1 were shown in Fig.5. Although the conversion to the sea breeze of the calculation at the points A, B, C, and D happened around 9:00, the conversion time of the observation was late 13:00. Moreover, the conversion to the land breeze of the observation at the points A and B was early compared with the calculation, and the observed wind velocity was also quite large compared with the calculation. However, the tendency of the calculated results and the observed data was good agreement in general.

5.2 Comparison of atmospheric pollutant concentration.

The diurnal variations of NO_2 , NO , O_3 , and SO_2 concentration were shown in Fig.6 ~ Fig.9, respectively. The mark ■ in these figures expresses the observed data, the solid line (Run1) the calculated results and the thin line (Run2) the calculated results except for the ship emission. (describe later) The calculated NO and NO_2 concentration at the points A and B was high compared with the observed data. Consequently, the calculated O_3 concentration was low compared with the observed data. It was considered that such a difference was occurred because the emission amount from ships in this area was estimated excessively. The observed data and the calculated results of NO , NO_2 , and O_3 at the points C, D, E, and F were in agreement in general. However, the calculated O_3 concentration at the point F was low compared with the observation. About SO_2 , the calculation and the observation were well in agreement at all points. As mentioned above, although some difference was still between the observation and the calculation, it was considered that the used numerical model had quite good accuracy.

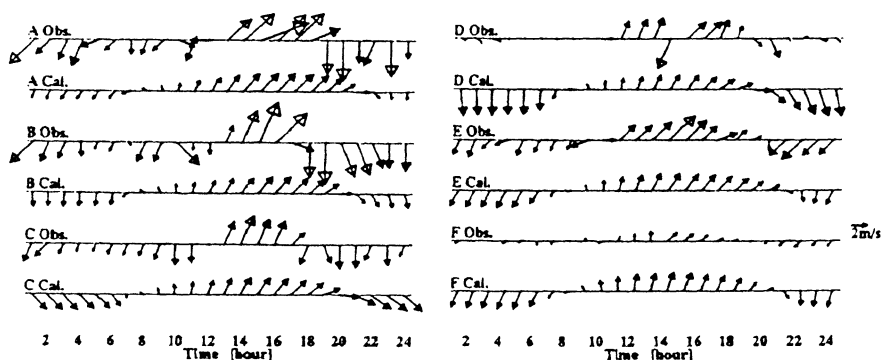


Figure 5 Diurnal variations of the observed and calculated wind vectors.

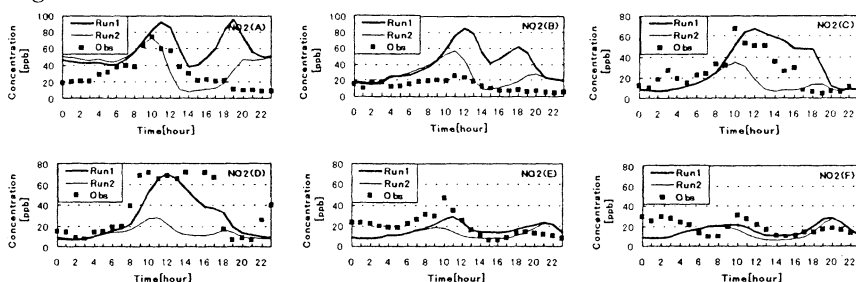


Figure 6 Diurnal variations of the observed and calculated NO_2 concentrations at six points. Boxes and solid lines denote the observed and calculated values, respectively. Thin lines denote the values calculated with no ship emission.

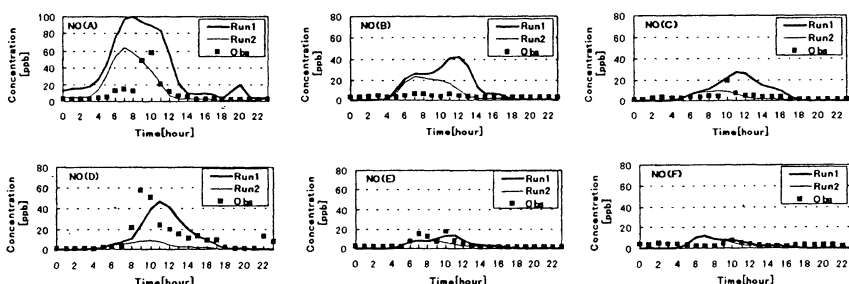
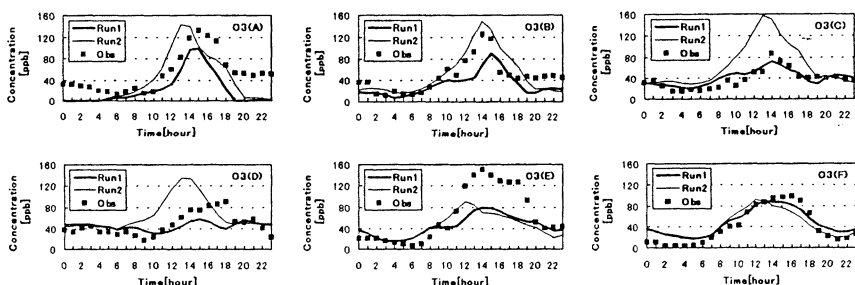
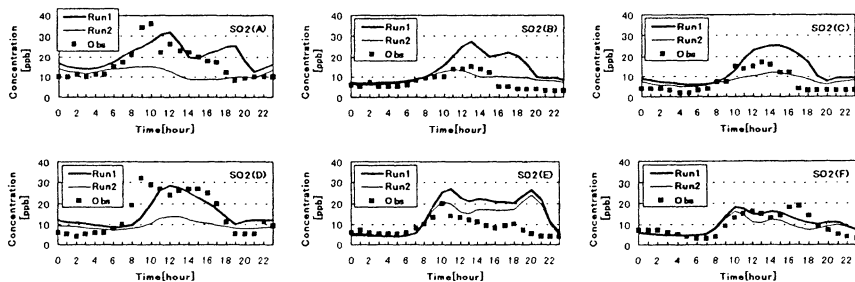


Figure 7 Same as Fig.6 but for NO.


Figure 8 Same as Fig.6 but for O₃.

Figure 9 Same as Fig.6 but for SO₂.

6 Emission influence from ships.

To investigate the rate of the contribution given to the atmospheric pollutant concentration by the emission amount from ships, the simulation was carried out except for the ship emission. The thin line (Run2) in Fig.6~9 showed these results. Since the pollutant from ships was conveyed ashore at the daytime which the sea breeze blew, NO, NO₂, and SO₂ concentrations of Run1 became high, compared with Run2. Next, from the calculated mean daily concentration at six observatories, the rate of the concentration contribution by the ship emission (RCCS) was estimated in Eqn.(4).

$$RCCS = \frac{A - B}{A} \quad (4)$$

where A is the concentration by the total emission, and B is the concentration except for the ship emission.

Consequently, although RCCS changed with the places, it became abbreviation 15~55 % by NO_2 and 17~39% by SO_2 . Moreover, O_3 concentration of Run2 became high compared with Run1. It is shown that the superfluous amount of NO_x emission causes the reduction of O_3 concentration. If HC emission reduction which is related to O_3 generation is not simultaneously carried out in performing NO_x emission reduction, there is a possibility that high O_3 concentration may occur. Next, to investigate the spatially influence that the emission amount from ships affects concentration, the concentration difference of Run1 and Run2 was searched for.

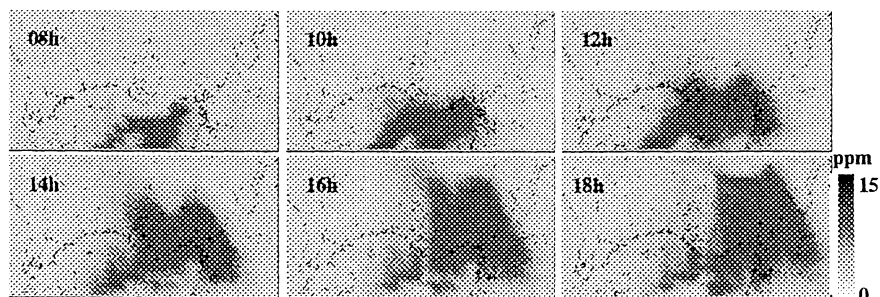


Figure 10 Influence of ship emission on NO_2 concentration at 2-hour intervals between 08:00 JST and 18:00 JST.

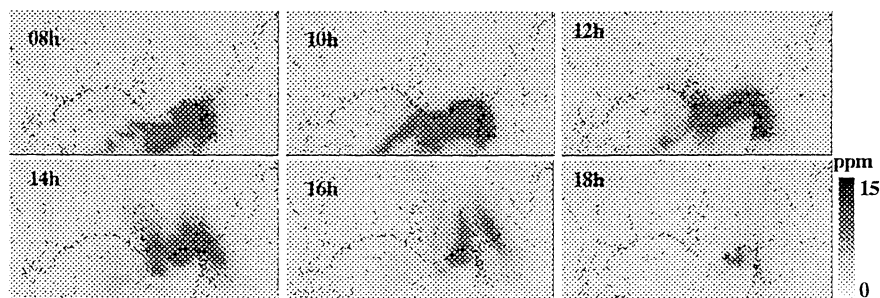


Figure 11 Same as Fig.10 but for NO.

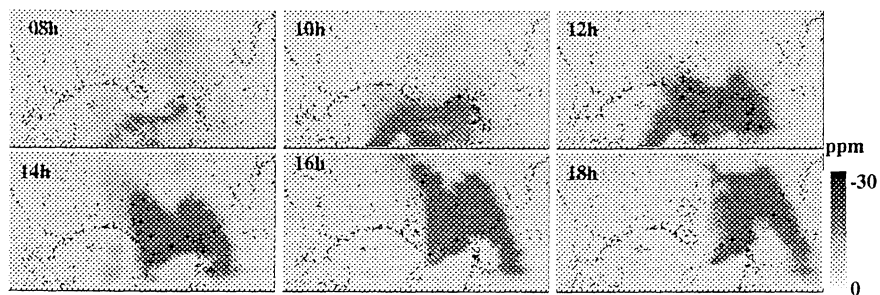


Figure 12 Same as Fig.10 but for O_3 .

The spatially distributions of NO_2 , NO and O_3 concentration difference at the height $z^*=20\text{m}$ were shown in Fig.10, 11 and 12, respectively. Till 12:00, the concentration rise region was limited to Hanshin area which the emission amount from ships was concentrating. Then, when the sea breeze blew off, the concentration rise region of NO_2 moved to inland, and the rise region exceeding 15ppb attained to 40km of inland at 16:00. Although the concentration rise region of NO also moved to inland, the concentration rise region was not large compared with NO_2 . Then the concentration rise region was not almost seen at 18:00. The concentration reduction region of O_3 and the concentration rise region of NO_2 were mostly in agreement. This can be guessed because the following reaction ($\text{O}_3 + \text{NO} \longrightarrow \text{NO}_2 + \text{O}_2$) is eminent and the net amount of NO_2 generation increased.

7 Conclusion.

It was shown that in Osaka bay area, the emission amount from ships of SO_x and NO_x occupied about 30 % of the total emission amount. The concentration prediction simulation was carried out using this emission amount data. When the estimated error of the emission amount data and the insufficiency of the flow field reappearance were taken into consideration, the calculated results and the observed data agreed reasonably. The second simulation was carried out except for the ship emission, and the emission amount from ships investigated the rate of the contribution given to the atmospheric pollutant concentration. When the sea breeze blew off, the concentration rise region of NO_2 moved to inland, and the rise region exceeding 15ppb attained to 40km of inland at 16:00. The concentration reduction region of O_3 and the concentration rise region of NO_2 were mostly in agreement. Thus, it was found that the influence of the ship emission on the atmospheric pollutant concentration was large. It will be required to find out the relation of the emission amount from ships and the concentration rise with the different conditions.

Acknowledgments. This work was supported partly by Grant-in-Aid for Science Research from the Ministry of Education, Science, Sports and Culture in Japan, and by Foundation of Nippon life Insurance Company.

References

1. Kondo, A., Yamaguchi, K. & Ahn, H.K., Simulation of Climatic Effects by construction of Reclaimed Island in Pusan, Korea, *Atmos. Environ.*, 30, pp.2437-2448, 1996.
2. Mellor, G.L. and Yamada, T., Development of a Turbulence Closure Model for Geophysical Fluid Problems, *Review Geophys.and Space Phys.*, 20, 851-875 1982.
3. Smolarkiewicz, P.K., A Simple Positive Definite Advection Scheme with Small Implicit Diffusion, *Mon. Wea. Rev.*, 111, pp.479-486, 1983.
4. Gery, M.W., Whitten, G.Z., Killus, J.P. and Dodge, M.C., A Photochemical Kinetics Mechanism for Urban and Regional Scale Computer Modeling, *J. Geophys. Res.*, 94, pp.12925-12956 1989.