B - 5.2 Modeling of material transport in the troposphere

Contact Person Masayasu Hayashi
Head, Interspheric Environment Section
Environment Assessment Division
National Institute for Resources and Environment
16-3, Onogawa Tsukuba, Ibaraki, 305 JAPAN
Phone +81-298-58-8380, Fax +81-298-58-8358
E-mail p1620@nire.go.jp

Total Budget for FY1991 - FY1993 23,323,000 yen (FY 1993; 8,456,000 Yen)

Abstract A three dimensional global transport model was developed unsing semi-Lagrangian transport scheme and analyzed meteorological data. The model was equipped with non-local diffusion of planetary boundary layer and total mass fixer which adjust time change rate depending on the increase or decrease of total mass. The model has 2.5 degrees horizontal resolution, 15 vertical sigma levels and makes global distribution of the constituent for every 6 hours.

Inter-hemispheric exchange time was about one year using ECMWF/TOGA advanced upper air data set of 1992 although vertical and horizontal diffusion associated with cumulus convection were not incorporated. Interhemispheric gradient of CFC-11 was simulated as 15 pptv which is consistent with ALE/GAGE observations.

Key words Troposphere, Chemical transport, Semi-Lagrangian, GCM

1. Introduction

The working group one of Intergovernmental Panel on Climate Change (WMO, 1990) predicted that the emission of greenhouse gas results in likely increase in global mean temperature in the next century. At the same time, it made a caution on the uncertainty in the prediction of the amount of constituent in the atmosphere, because of the uncertainty in the source and sink of the greenhouse gasses. Recent study of the global distribution of carbon dioxide [(1)] indicates that the deduction of the source and sink of the gasses requires three dimensional transport model as well as the data on the continents.

2. Research Objectives

The primary objective of this study is to investigate the mechanism of transport of the materials in the global atmosphere. The secondary objective is to provide a handy three dimensional transport model for modeling research like boundary processes or chemical reactions.

3. Research Method

The development of transport model was designed in three steps: (1) transport calculation (2) vertical transport by cumulus convection and (3) planetary boundary layer.

A transport calculation is designed using wind data analyzed at the European Center for Medium-Range Weather Forecasts(ECMWF). A sensitivity study is done with the data produced by Community Climate Model(CCM) of the National Center for Atmospheric Research (NCAR). A trajectory model and a constituent model are developed using Lagrandian method and semi-Lagrangian transport scheme, respectively.

An artificial material was used to investigate interhemispheric exchange which is closely related to the diffusion in the tropics associated with vertical mass transport of cumulus convection. A vertical transport scheme created by Albrecht is investigated in the CCM/NCAR.

Non-local planetary boundary layer is used at the lower layers to reproduce time delay of the surface emission to the middle of the troposphere. This time delay makes the vertical gradient of the constituent and seasonal variation of the mixing ratio in the planetary boundary layer. Total mass fixer is used to eliminate drift of the amount in the transport calculation.

4. Results

(1) Meteorological data

We have developed a tracer transport model using meteorological data analyzed to give the initial conditions for the ECMWF numerical weather prediction system. The advantage of this method over an online system is that we can incorporate the effect of the interannual variation of meteorological conditions. We used three types products from ECMWF. One year from ECMWF/WMO, three years from ECMWF/TOGA Basic level IIIb, and one year form ECMWF/TOGA Advanced Upper air data set. The final product of this project is using the last data because the TOGA data contain gravity wave associated with cumulus convection and the Advanced Upper air data sets are given most frequently (6 hours) [(2)]. The data were given on 15 pressure levels (1000 925 850 700 500 400 300 250 200 150 100 70 50 30 10 hPa).

(2) Semi-Lagrangian Transport

Transport of a tracer using wind field data was expressed in a semi-Lagrangian form [(3)]. The mixing ratio of a tracer at a point in time was estimated from the mixing ratio at the departure point. In this scheme, a departure point of an air parcel at a grid point is calculated at each time step when a wind fields are given.

The disadvantage of using meteorological data derived from observations is that we must accurately estimate the data by interpolation at a time between that of the observations.

For the sensitivity study of the trajectory calculation using temporally sparse data, horizontal wind data of CCM/NCAR obtained at each time step were used. The comparison of departure points obtained by 30 minutes wind interval and those by the wind interpolated into each 30 minutes from the wind of 12 hours interval, showed about 7 degrees difference in upper part of the middle latitude troposphere.

The departure point six hours before is located in the lattice, usually not at a grid point. The mixing ratio of the departure point was estimated by linear interpolation from the surrounding lattice. The backward trajectories were calculated using pressure coordinates. The lowest sigma level used for calculating tracer mixing ratios in the model was used for comparison with ground observations of trace gas mixing ratios. Fifteen sigma coordinates (0.975 0.925 0.875 0.775 0.6 0.45 0.35 0.275 0.225 0.175 0.125 0.085 0.06 0.04 0.02) were adopted for calculating the mixing ratio of tracers.

(3) Vertical transport by cumulus convection

For the preparation of the modeling, we have incorporated a mass transport scheme in NCAR/CCM1 [(4)].

Vertical transport of constituents influenced the interhemispheric exchange time [(5)]. Interhemispheric exchange time in the model using ECMWF/TOGA Basic data was about one year [6] which is the value adjusted by diffusion radius in the previous studies [5]. Thus, we have not incorporated this mechanism in our model.

(4) Planetary Boundary Layer

A Planetary Boundary Layer(PBL) was incorporated into a transport model in a simple way. The height of the PBL was obtained by estimating the bulk Richardson number at each layer of the model _[7] The bulk Richardson number was calculated as follows

$$Ri = \frac{gz(\theta(z)-\theta_s)}{t(z)v(z)^2} \tag{1}$$

where g is gravitational acceleration, z is height, $\theta(z)$ is the potential temperature at height z, $t(z)$ is the temperature, θ_s is the surface potential temperature and $v(z)$ is the wind speed.

The layers with a Ri less than 0.25 were assigned as being part of the PBL. Trace gases released at the surface were distributed over all the layers in the PBL immediately.

(5) Mass fixer

The total mass in the semi-Lagrangian model can not be conserved exactly because of the need to interpolate tracer concentrations. A mass fixer was applied to keep total mass constant between advection steps in the model.

The total mass of a constituent is calculated as

$$A(t) = \sum_{all} c(x,t)w(x,t) \tag{2}$$

where $c(x,t)$ is the *mass* mixing ratio of a constituent and $w(x,t)$ is the weight of the atmosphere at position x at time t(hour). If the total mass has changed then the amount was adjusted using the following procedures. If $A(t+6)>A(t)$ then $A(t+6)$ [all] is partitioned into two parts; one with the summation over the grid points with positive change[+]. The other is that with zero change or negative change[0,-]. Then a coefficient α was calculated by

$$\begin{aligned} &\sum_{0,-} c(x,t+6)w(x,t)+\sum_{+} c(x,t)w(x,t) \\ &+ \alpha\sum_{+}(c(x,t+6)-c(x,t))w(x,t) \\ &= \sum_{+,0,-} c(x,t)w(x,t) \ . \end{aligned} \tag{3}$$

The mixing ratio is adjusted by

$$c^{adj}(x,t+6) = c(x,t)+\alpha(c(x,t+6)-c(x,t)) \ . \tag{4}$$

at [+]. When $A(t+6)<A(t)$, the adjustment was applied to the grid points where the values were reduced [-]. The time variation of $w(x,t)$ was ignored.

(6) CFC-11 simulation

Global distribution of CFC-11 was calculated with this model with a fixed horizontal distribution [8] and interannual variation of total emission [9] without distraction in the stratosphere.

Global amount in the model atmosphere was not exactly the same with calculated from the integration of surface fluxes. A coefficient was multiplied globally to adjust this discrepancy. Interhemispheric gradient was about 15 pptv, which is consistent with ALE/GAGE observation [9]. In the simulation with zero in the stratosphere and observed amount in the troposphere, stratospheric turn around time was about 3 month, which is too short compared with the value in the literatures.

(7) Speed of the model

The departure points were stored in a file and were used for repeating the transport calculation later. The backward trajectory analysis was the most computationally time consuming procedure in performing a simulation of the evolution of the concentration of a tracer with time. It takes 6 hours per month of wall clock time on a Sparc Station 10/512MP, while the calculation of the distribution of a tracer for a prescribed sources/sinks using pre-calculated trajectories can be performed in 2 hours of wall clock time per year.

5. Discussion

The model developed in this project has an attractive feature in term of interhemispheric exchange. This feature depends on the quality of the analyzed wind used in the model. There are some deficiencies in the model. First of all, troposphere and stratosphere exchange processed is too fast (3 months) compared with the standard value in the literature (2 years). The second is that the amount of the emission given at the surface is not automatically enter into the model atmosphere.

For the simulation of minor constituent in the troposphere there deficits are not critical. Therefore, this model can be used to simulate global distribution of global warming materials. The simulation of each component can be used in the inversion calculation to evaluate the strength of each source.

References

1) Tans, P. P., T. C. Conway and T. Nakazawa, 1989: Latitudinal distribution of the sources and sinks of atmospheric carbon dioxide derived from surface observations and an atmospheric transport model. *J. Geophys. Res.*, **94**, 5151-5172.

2) Trenberth, K. E., 1992: Global analyses from ECMWF and atlas of 1000 to 10mb circulation statistics. *NCAR Tech. Note, NCAR/TN-373+STR,* Boulder, CO., U.S.A., 191pp.

3) Brasseur, G., P., and S. Madronich, Chemistry-transport models, In *Climate system modeling,* K. Trenberth (ed.) Cambridge University Press, 788pp, 1992.

4) Taguchi, S. and J.Hack, 1993: The effect of convective and cloud processes on the CCM simulated climate,
NCAR Tech. Note, NCAR/TN-393+STR, Boulder, CO., U.S.A., 114pp.

5) Prather, M., M. McElroy, S. Wofsy, G. Russel and D. Rind, 1987: Chemistry of the global troposphere: Fluorocarbons as tracers of air motion. *J. Geophys. Res.*, **92,** 6579-6613.

6) Taguchi, S., 1993: Inter-hemispheric exchange in the troposphere by an atmospheric transport model based on observed winds. *J. Meteoro. Soc. Japan,* **71,** 123-135.

7) Troen I. and L. Mahrt, A simple model of the atmospheric boundary layer; Sensitivity to surface evaporation. *Boundary-Layer Meteorology,* **37,** 129-148, 1986.

8) Hartley D. and R. Prinn, Feasibility of determining surface emissions of trace gases using an inverse method in a three-dimensional chemical transport model. *J.Geophys.Res.*, **98,** 5183-5197, 1993.

9) *Trends'91: A Compendium of data on global change,* Carbon dioxide information analysis center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, T. A. Boden, R. J. Sepansk and F. W. Stoss, ed., 1991.