Atmospheric Composition Change and Its Climate Impact Studied by Global and Regional Chemical Transport Models

Group Representative

Hajime Akimoto Frontier Research System for Global Change

Authors

Shamil Maksyutov [*1] ・ Oliver Wild [*1] ・ Hajime Akimoto [*1]

[*1] Frontier Research System for Global Change

Atmospheric composition change studies with advanced parallel chemical transport models were conducted. Global chemical transport model based on off-line transport has been developed to run at T63 and T106 resolutions, and applied to studies of the atmospheric composition over Pacific. A detailed 64-region inverse model of atmospheric transport was developed to simulate the interannual CO_2 flux variability during 90's. Results reveal more details in connection between simulated fluxes, observations and environmental variables (temperature, rain, fire) than was seen before. The oceanic CO_2 flux anomalies appear to be closely correlated with the primary modes of climate variability such as the Pacific Decadal Oscillation (PDO), El Niño/Southern Oscillation (ENSO), North Atlantic Oscillation (NAO) and Arctic Oscillation (AO). A detailed comparative evaluation of the satellite based CO_2 observation approaches was performed with inverse model grid of 18×24 regions.

Keywords: atmospheric composition change, global chemical transport model, carbon monoxide, inverse model, carbon dioxide

1. Global chemical transport model study

Studies with regional-scale chemistry models demonstrate that spatial resolutions of the order of 20 km or finer are required to accurately simulate oxidant formation in polluted urban regions. Current global models of tropospheric chemistry as used in the recent IPCC Third Assessment Report [2001] to simulate ozone, the third most important greenhouse gas and a major contributor to urban pollution, typically have a spatial resolution of 200–500 km, far in excess of that required to correctly simulate the timescales for its formation and destruction. The non-linearity in ozone production may be tackled in two ways: by increasing the spatial resolution of current chemistry models to determine the sensitivity of ozone production at these scales, and by introducing new parameterizations to deal with processes occurring below the grid-scale of global models. This project is using a combination of these techniques and is expected to result in more reliable global simulations of tropospheric ozone than current models are capable of, thus reducing the uncertainty in assessments of the global and regional impacts of ozone on climate and air quality.

The FRSGC/UCI Global Chemical Transport Model has been successfully ported to the Earth Simulator and results have been evaluated against those from an SX5. The CTM is run at T63 (1.9 degree) resolution with 40 vertical levels and is optimized for the NEC vector processors of the SX5 and ES. The figure shows the distribution of carbon monoxide (CO) in the boundary layer behind a frontal system over the western Pacific Ocean on 4th March 2001. The features are picked up much more clearly at T63 resolution than at T21 (5.6 degrees), and match aircraft and satellite observations during the NASA TRACE-P campaign well, but the resolution is still insufficient to elucidate the key mechanisms that control the outflow of east Asian pollution across the Pacific. To tackle this problem, the model has been upgraded to run at T106 (1.1 degree) resolution, and we are currently waiting for appropriate off-line meteorological fields to drive it. Once calculation with these fields is completed, the simulations will match or exceed the highest resolution that global chemical models have previously been run at. Parallelization of the CTM is currently in progress; the model runs well on 8 processors on a single node using OpenMP, and work is now under way to extend its capabilities using MPI to run on multiple nodes while retaining OpenMP for intra-node processing. While the scalability of the code is good for dynamics and for chemical algorithms, a number of bottlenecks remain, particularly in diagnostic code and in sections requiring large quantities of input data. Future optimization will focus on these sections to ensure that high performance can be achieved.

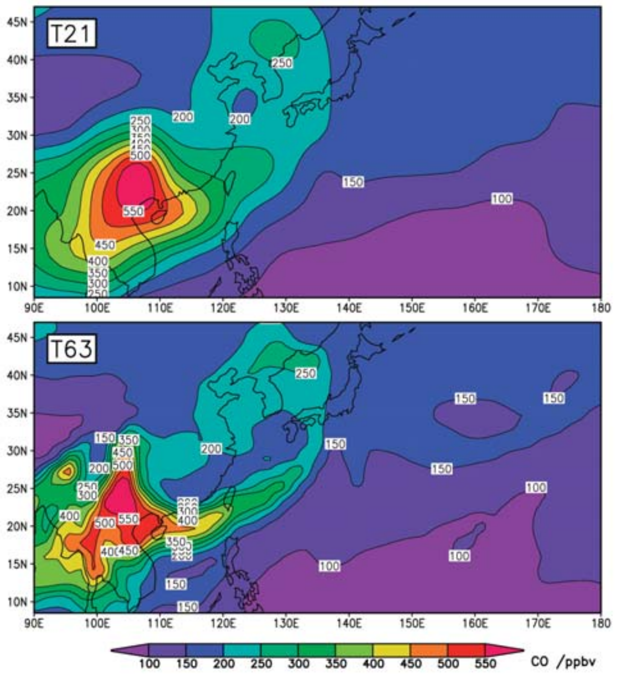

Fig. 1 Boundary layer CO over the western Pacific Ocean on 4th March 2001. Features such as the banding of CO in outflow behind a cold font are captured at T63 resolution, and allow the long-range transport of this CO to be followed much more reliably than at T21.

2. Off-line transport model development.

The off-line atmospheric tracer transport model (NIES/FRSGC) was further modified and tuned to run on multiple nodes in parallel using message passing interface, where non-reactive individual tracers are run using different processors, but using common weather preprocessing module. Although distribution of functions requires manual load-balance tuning, the CPU time decreased by 30–40% for usual simulations. The improved model demonstrates parallelization efficiency of 75% on 10 nodes (80 PEs) for typical model application.

NCEP reanalysis data at 2.5 degree resolution were preprocessed for multiyear simulations. Multi-year model runs were performed at 1×1 degree horizontal resolution with daily CO_2 fluxes, tuning the vertical mixing led to improvements on simulation of the CO_2 seasonal cycles and synoptic scale variability at observation locations. To counter increased computation demand at 1×1 degree resolution, within-node parallelization (automatic by compiler) was applied with 50% efficiency, achieving 4 times speedup with 8 processors.

3. Inverse model study of the interannual variation in the CO_2 fluxes.

The inverse modeling of carbon dioxide (CO_2) is often restricted to lower spatial resolution (e.g. 22 partitions of the globe), and uses transport model simulations using cyclo-stationary meteorological fields due to the limitation of computational resources. Following the installation of the Earth Simulator and the development of the parallel transport model, we have increased the spatial resolution of the inverse model to 64 regions, the land area by about 4 times (42 regions) and twice for the 22 ocean regions. Moving to higher resolution increases the degrees of freedom for the regional flux functions to fit the CO_2 observations, which is otherwise hindered by the so called "aggregation error". In addition to this we have used interannually varying (IAV) meteorological fields from the NCEP/NCAR reanalysis dataset. The use of reanalyzed meteorological parameters to a large extent accounts for the effect of changes in synoptic scale transport pattern on CO_2 concentration due to the prevailing mode of climate oscillations, such as ENSO in the equatorial latitudes or AO in the northern high latitudes[1)]. Figure 2 shows the improvement in ability of more detailed inverse model to fit the observed CO_2 concentration variations.

Analysis of CO_2 flux estimations showed that the terrestrial ecosystem and oceanic uptake during the 1990s were about 1.15 ± 0.14 and 1.88 ± 0.18 Pg–C yr^{-1}, respectively. Our results suggested that forest fires have contributed largely to the enhanced CO_2 emission from the land regions in the tropical latitudes during the 1997/1998 El Niño event. The oceanic CO_2 flux anomalies appear to be closely correlated with the primary modes of climate variability such as the Pacific Decadal Oscillation (PDO), El Niño/Southern Oscillation (ENSO), North Atlantic Oscillation (NAO) and Arctic Oscillation (AO). We believe the interannual variability in global and regional fluxes are captured more realistically in this work since the information from a greater number of observation stations have been utilized under this modified inverse model framework.

4. Inverse model application to evaluation of the proposed column CO_2 observations.

Inverse modeling of the regional flux patterns of atmospheric CO_2 is a useful tool for evaluation the contribution of new observation concepts, sensors and systems for improvement of the local or global knowledge of the carbon dynamics. When applying such approach to the evaluation of the space-based sensors[2)], much higher resolution (smaller region sizes) is required. By applying a parallel model, the number of the source region was increased to 432 (15×10 degree grid) and more robust evaluation of the column CO_2 observations with satellite sensors was achieved[3)]. The analysis suggest that sensors capable of observing the lower tropospheric CO_2 signal over continent are most desirable for constraining the global CO_2 flux budgets.

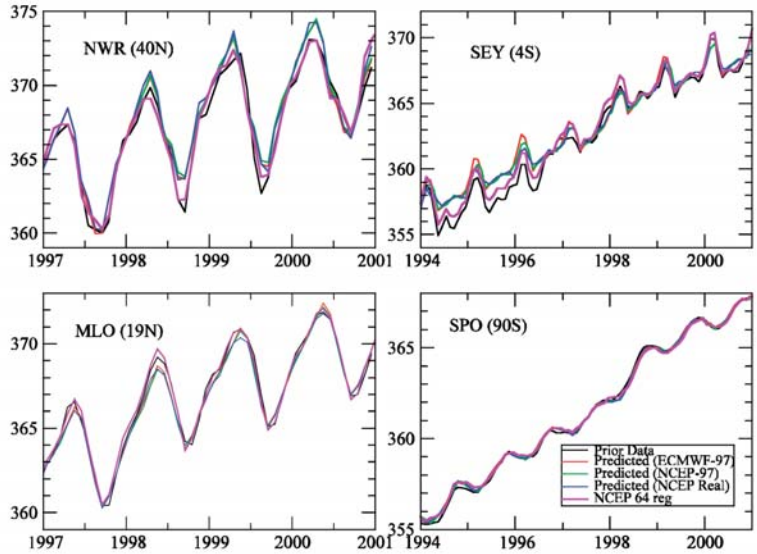

Fig. 2 Effect of using interannually varying fields and higher spatial resolution inverse model on source information gathering. The source information is then analyzed to study the interannual variability in CO_2 flux anomalies. The inverse model results with 64 regions and IAV winds (magenta line) produced best fit to the observed CO_2 data at all stations. The comparisons at Niwot Ridge (NWR), Seychelles (SEY), Mauna Loa (MLO), and South Pole (SPO) are shown.

References

1) P. K. Patra, S. Maksyutov, M. Ishizawa, and T. Nakazawa, Interannual variability in ocean and land CO_2 fluxes derived using Time Dependent Inverse model, EOS. Trans. AGU, 84(46), Fall Meet. Suppl., Abstract A52B-0792, 2003.
2) P. K. Patra, S. Maksyutov, G. Inoue, H. Nakajima, Y. Sasano, T. Nakazawa, An evaluation of Solar-Occultation FTS for Inclined-orbit Satellite (SOFIS) observations with source inversion of CO_2, J. Geophys. Res., 108, D24, 4759, doi:10.1029/2003JD003661, 2003.
3) S. Maksyutov, P.K. Patra, and G. Inoue, Pseudo-data inversion of column-CO_2 observations by remote sensing using a high resolution inverse model, Int. Arch. PRS and SIS, v. XXXIV, 7/W14, pap. No. J-2, 2003.