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

Project Representative

Hajime Akimoto Frontier Research Center for Global Change, Japan Agency for Marine-Earth Science and Technology

Authors

Shamil Maksyutov *1, Takashi Maki *2, Oliver Wild *1 and Hajime Akimoto *1

*1 Frontier Research Center for Global Change, Japan Agency for Marine-Earth Science and Technology

*2 Japan Meteorological Agency

A high-resolution (64-region) time-dependent inverse model (TDIM) using forward model simulations with the inter-annually varying (IAV) meteorology from NCEP/NCAR reanalysis and atmospheric CO_2 observations from up to 100 stations. was applied to simulate inter-annual variations in CO_2 source sink fluxes. Our analyses suggested that while ENSO is the single largest controlling factor for inter-annual and decadal variability in land and oceanic CO_2 fluxes, the effect of Mt. Pinatubo aerosols on the terrestrial ecosystem can also be detected.

The off-line carbon dioxide transport model (JMA-CDTM) was successfully ported to Earth Simulator and tuned to run on multiple nodes in parallel using message-passing interface.

Keywords: atmospheric composition change, chemical transport model, inverse modeling, forward modeling, carbon dioxide

a. Time-dependent inverse model

Last year we reported the development of a high-resolution (64-region) time-dependent inverse model (TDIM). This TDIM uses forward model simulations with the inter-annually varying (IAV) meteorology from NCEP/NCAR reanalysis and atmospheric CO_2 observations from up to 100 stations. Use of IAV meteorology helps for better simulations of the inter-annual variations in CO_2 concentrations due to the change in transport caused by the climate oscillations such as the El Niño Southern Oscillation (ENSO), North Atlantic Oscillation (NAO). Thus we avoid a potential misattribution of CO_2 sources and sinks at regional or global scales. While our analyses suggested that ENSO is the single largest controlling factor for inter-annual and decadal variability in land and oceanic CO_2 fluxes, the effect of Mt. Pinatubo aerosols on the terrestrial ecosystem can be detected (Fig. 1). During

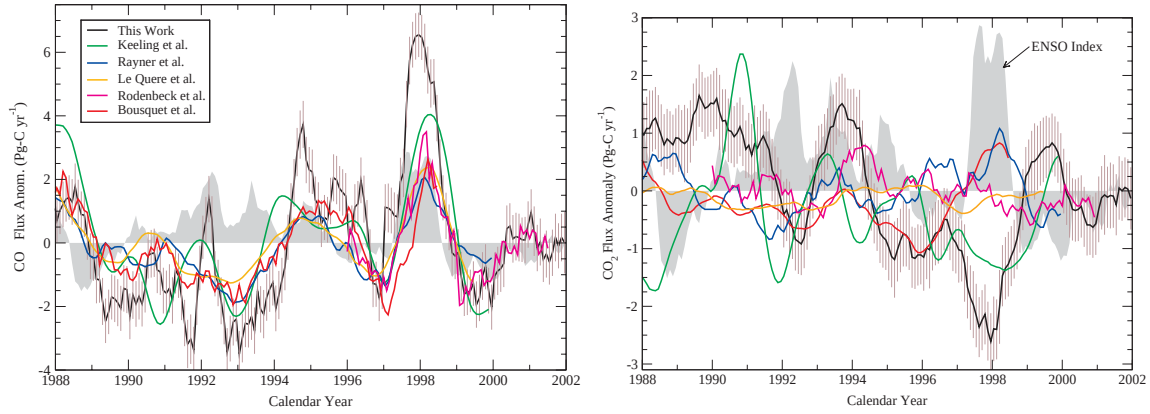

Fig. 1 Comparison of 64-region TDIM derived fluxes (This Work) and several other published results for global land (a: left panel) and ocean (b: right panel) are shown. The vertical bars indicate TDIM estimated a posteriori flux uncertainties for This work only using atmospheric CO_2 data from 87 stations. The modeling approached used in different studie vary widely; e.g., Rayner et al., Bousquet et al. and This work use Bayesian inversion but the inverse model resolution and observational data network are different. Keeling et al. used double deconvolution method, Rodenbeck et al. adopted an adjoint model based inversion. Results of Lequere et al., are forward model based.

the warm ENSO period tropical ocean (mainly East Equatorial Pacific) upwelling is suppressed because of the increased thermal stratification in the upper ocean, and that led to the negative oceanic flux anomalies in 1992 and 1997 (Fig. 1b). The same situation creates a drier and warmer surface condition over the tropical land which produced enhanced emission of CO_2 (positive flux anomaly) due to lesser photosynthetic uptake and increased heterotrophic respiration by the plants, and biomass burning of dry matter (Fig. 1a) as seen during 1992, 1994 and 1997. Large amount of aerosols loading into the atmosphere following the Mt. Pinatubo eruption in June 1991 the terrestrial uptake of CO_2 increased by suppressed respiration and enhanced photosynthesis during period 1991–1993. This is due to the lower ground temperature and enhanced diffused radiation at the tree level caused by the aerosol scattering of the sunlight. All these features are most consistently captured by our TDIM using the observations at 87 stations when compared with the other published results (see Fig. 1).

b. Development of high-resolution tracer transport model.

We have developed a high resolution chemical/tracer transport model (CTM) for better representation of atmosphere CO_2 data in space and time. In the coarse resolution model (typically 2×2 degrees) often the measurement locations are not well separated from the point sources, land-ocean boundary is ill defined or the heterogeneity in sources is not represented appropriately. To account for these problems we have designed a CTM that can run at variable horizontal resolutions (e.g., 1×1, 0.5×0.5, 0.25×0.25 degree). This version of the CTM has 47 vertical layers with several of them usually within the planetary boundary layer (PBL). The PBL is varied diurnally using the 3-hourly boundary layer heights from the ECMWF reanalysis and operational forecast model. The higher horizontal resolution is achieved by domain decomposition of the global grid into up to 180 latitude bands. The domain boundary data are exchanged by MPI interface. Preliminary results from this high-resolution model show significant improvements both in horizontal contrast and diurnal cycles of concentration profile in lower troposphere. Surface flux inventories combine lower resolution natural CO_2 fluxes with high resolution anthropogenic emissions. Currently we are testing our simulation results by comparing with high-frequency observations (hourly time step) for Transcom continuous data intercomparison experiment.

c. CO_2 simulation experiment at 1×1 degree resolution with JMA-CDTM transport model.

The off-line carbon dioxide transport model (JMA-CDTM) was successfully ported to Earth Simulator and tuned to run on multiple nodes in parallel using message-passing interface. Horizontal transport scheme of the JMA-CDTM is Semi-Lagrangian scheme and vertical mixing scheme is an offline version of JMA global spectral model. The model uses 6 hourly-analyzed meteorological fields to transport tracers.

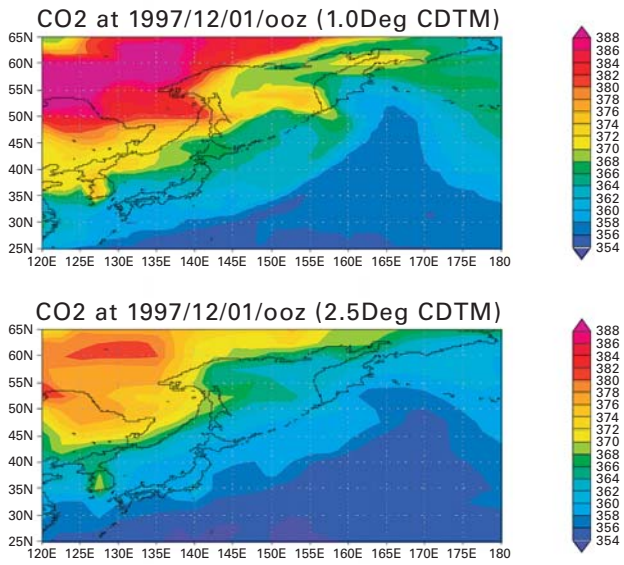

Fig. 2 Simulated surface CO_2 concentrations in different resolution of JMA-CDTM.

The improved model demonstrates parallelization ratio of about 99.5% on 10 nodes (80 PEs) for typical model application. Also we have modified our model code to achieve higher vectorization ratio. Finally, the vectorization ratio of the model achieves 99.4% on 10 nodes (80 PEs). As we can treat each tracer independently in inverse modeling that can estimate regional carbon fluxes from observational data, we can divide more number of the source region without lessen the parallelization ratio.

To obtain model transport matrix for inverse modeling, we have prepared high- resolution (1×1 degree, 32 layers, 6 hourly) meteorological dataset from 1990 to 2002 using MJ-98 GCM nudging with ERA-40 re-analysis.

We have upgraded the horizontal resolution of JMA-CDTM from 2.5×2.5 degree to 1×1 degree on Earth Simulator. Upgraded model can represent smaller scale disturbance with higher resolution meteorological dataset that we have prepared (Figure 2). We have a plan to analyze regional scale carbon flux history using two transport models (FRCGC/NIES and JMA-CDTM) with similar experimental conditions in order to estimate the uncertainty of the carbon cycle analysis due to the model difference.

d. Fully chemistry coupled global chemical transport model

The FRCGC/UCI Global Chemical Transport Model is now running on the ES at T63 (1.9 degree) resolution on 8 processors. The model has been upgraded to run at T106 (1.1 degree) resolution, and this has now been thoroughly

tested on the FRCGC SX5 system with T159 meteorological data that has recently been made available by the ECMWF. We are now working on porting the data and code upgrades to the ES system.

Bibliographies

1) Patra, P.K. S. Maksyutov, M. Ishizawa, T. Nakazawa, G. Inoue, Effect of biomass burning and meteorological conditions on land -atmosphere CO_2 flux from atmospheric CO_2 inverse modelling, Global Biogeochem. Cycles, 2004 (in press).

2) Patra, P.K. S. Maksyutov, M. Ishizawa, T. Nakazawa, J. Ukita, T. Takahashi, Interannual and decadal changes in the sea-air CO_2 flux from atmospheric CO_2 inverse modeling, Global Biogeochem. Cycles, 2004 (in press).

全球・地域スケール化学輸送モデルによる大気組成変動とその気候影響の研究

プロジェクト責任者
秋元　肇　海洋研究開発機構・地球環境フロンティア研究センター
著者
シャミール・マクシュートフ*1，真木　貴史*2，オリバー・ワイルド*1，秋元　肇*1
*1　海洋研究開発機構・地球環境フロンティア研究センター
*2　気象庁観測部環境気象課

a. 時間依存逆モデル

NCEP/NCAR再解析データ及び世界中の100地点のCO_2観測データを用いた年々変動前進シミュレーションに基づく高分解能(64地域)時間依存逆モデルが開発され、これを用いたCO_2濃度の年々変動のシミュレーションが行われた。本解析の結果らは、陸域及び海域のCO_2フラックス変動に対しては単一要因としてはENSOの影響が最も大きいが、ピナツボ火山からのエアロゾルによる陸域生態系への影響も検出された。

b. 高分解能トレーサー輸送モデルの開発

これまでの中分解能モデルに比べてCO_2の空間的・時間的変動をよりよくシミュレートできる高分解能化学トレーサーモデル(垂直分解能47層、水平分解能1×1, 0.5×0.5, 0.25×0.25 度)が開発された。本モデルによる予備的計算の結果では、従来の中解像度モデルに比較し、水平コントラスト、日変化などがよりよく表現されることが分かった。

c. JNA-CDTM輸送モデルによる1×1度CO_2シミュレーション実験

気象庁の二酸化炭素オフラインモデル(JMA-CDTM)の地球シミュレーターへの移植がなされた。本モデルの水平分解能を従来の2.5 × 2.5 度から 1 × 1 度へと高め、両者によるCO_2濃度分布の比較を行うとともに、FRCGC/NIESモデルとJMA-CDTMモデルによる炭素循環解析の比較検討計画の立案を行った。

d. 化学フル結合による全球化学輸送モデル

大気中の化学反応を全て取り込んだ化学フル結合による全球化学輸送モデル FRCGC/UCIモデルが、地球シミュレータ上でT63(1.9×1.9 度)からT106(1.1×1.1 度)へ高解像度化された。現在、新しいモデルの計算結果と高解像度気象モデルを用いた従来のモデル計算結果との比較検証がなされている。

キーワード：大気組成変化，化学輸送モデル，逆モデル，前進モデル，二酸化炭素