Atmospheric Composition Change and its Climate Effect Studied by Chemical Transport Models

Project Representative

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

Authors

Prabir Patra *1, Kentaro Ishijima *1, Masayuki Takigawa *1, Shamil Maksyutov *2, Takashi Maki *3 and Hajime Akimoto *1

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

*2 National Institute for Environmental Studies

*3 Japan Meteorological Agency

The main aim of this project is to execute forward and inverse modeling of atmospheric greenhouse gases (e.g., CO_2, CH_4, N_2O) with the aid of atmospheric transport models. The CCSR/NIES/FRCGC atmospheric general circulation model (AGCM) nudged with ECMWF or NCEP analyzed meteorological fields are used for forward simulations of GHGs and dynamical tracers (Radon-222, SF_6). The horizontal resolution of the model varied from ~1 × 1 degree to ~2.8 × 1.8 degrees and vertical layers from ~15 to 67 (troposphere-mesosphere). The 67-layers version of the AGCM is run for the gases with chemical loss (N_2O, CFC-12, CH_4). Without accounting for the stratosphere-troposphere exchange effect, the observed seasonal cycle of surface N_2O are not simulated well. This study suggests that the troposphere and stratosphere should be treated as a tightly coupled system for improved simulation of GHGs.

Higher resolution anthropogenic CO_2 emissions are synthesized from 1 × 1 degree emission inventory, enhanced with 2.5 min global population map data, and combined with lower resolution terrestrial ecosystem and oceanic flux data. Different horizontal resolution runs showed that, for example, 0.25 × 0.25 model resulted more vivid city plumes than from 2 × 2 model.

The time-dependent inversion inter-comparison was prepared by using the off-line carbon dioxide transport model (JMA-CDTM) with 1.0 × 1.0 degree in horizontal resolution. Monthly mean fluxes of CO_2 from 1993 to 2003 were estimated using the model.

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

1. Forward and inverse modeling of GHGs using AGCM

The 67-layers version of the AGCM is run for the gases with chemical loss (N_2O, CFC-12, CH_4). We find the N_2O-depleted stratospheric air can reach as low as the earth's surface in summer at high latitude (Fig. 1). Since photochemical loss of N_2O is strongest in the summer hemisphere, we obtained largest stratosphere-troposphere exchange (STE) flux even though it is well-known that maximum downwelling of stratospheric air occurs within the winter polar vortex. Without accounting for the STE effect the observed seasonal cycle of surface N_2O are not simulated well. This study suggests that the troposphere and stratosphere should be treated as a tightly coupled system for improved simulation of GHGs. Currently, not many chemistry-transport models (CTMs) employ such configuration.

For the inverse modeling purpose our simulation of a suite of chemical species (CO_2, N_2O, CFC-12, CH_4) and dynamical

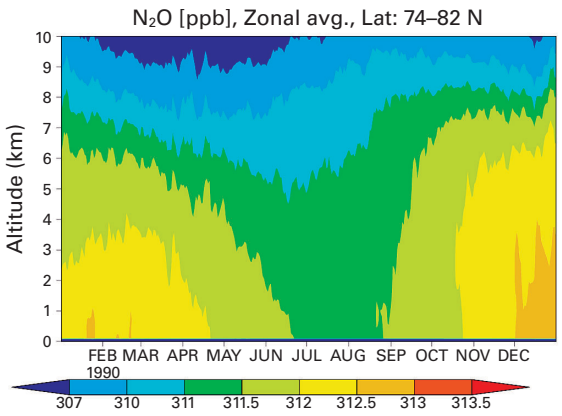

Fig. 1 Example to stratosphere-troposphere exchange of N_2O in the boreal summer high latitude during the year 1990. The tropopause heights vary between 8 and 10 km at this latitude band during winter and summer, respectively.

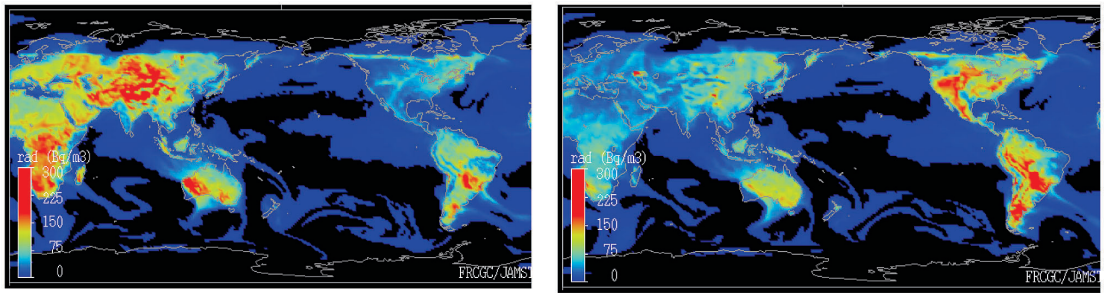

Fig. 2 Diurnal variations in Radon-222 at the surface, arising due to atmospheric dynamics (low PBL high Radon and vice versa), as simulated by the AGCM for 01 July 2002 at 00 UT (left) and 12 UT (right). Annual mean surface fluxes are used in this simulation and Radon decays in the atmosphere with a half-life of 3.8 days.

tracers (SF_6, Radon) are likely to decipher the major deficiencies in our understanding; whether that is source/sink inventories or atmospheric transport for simulating the atmospheric-CO_2 concentrations. Figure 2 shows the diurnal variation in Radon-222 concentrations using the CCSR/NIES/FRCGC AGCM at T106 (32 vertical layers) resolution. Note that the diurnal variation in concentration is generated by the atmospheric dynamics only (no variation in fluxes). Since the GCM dynamics has well behaved diurnal variations in planetary boundary layer (PBL) etc. forward model simulations using this model would lead to significant improvement in the source/sink estimations of GHGs, CO_2 in particular.

2. CO_2 simulation with a higher resolution model

Presently, there is much interest in incorporating continuous CO_2 data into inversions to estimate the CO_2 sources and sinks. Such study assumes that transport (forward) models are able to adequately simulate CO_2 concentrations at diurnal and synoptic timescales. However, this assumption may not be true as many transport models are running at coarse resolutions like 2° longitude-latitude, and mesoscale variations are difficult to resolve in such resolutions. Here we present a new version of the global atmospheric tracer transport model (NIES05) capable of running globally at the grid resolution up to 0.25° longitude-latitude. The surface CO_2 fluxes used in this study is specified by Transcom continuous experiment protocol, include seasonally varying oceanic flux, a SiB2 diurnally varying terrestrial ecosystem fluxes, and fossil fuel emissions. Higher resolution anthropogenic CO_2 emissions are synthesized from 1 × 1 degree emission inventory, enhanced with 2.5 min global population map data, and combined with lower resolution terrestrial ecosystem and oceanic flux data. The vertical resolution is enhanced to 47 levels for better resolving the mixing processes in the boundary layer, driven by 3-hourly PBL height data of ECMWF. Four types of horizontal resolution (2 × 2, 1 × 1, 0.5 × 0.5 and 0.25 × 0.25) have been tested.

Figure 3 shows the surface CO_2 distributions in East Asia at the resolutions of (a) 2 × 2 and (b) 0.25 × 0.25 degree. Although the area-average concentration values are almost the same in Figure 3 (a) and (b), distribution shapes are quite different from each other. For example, 0.25 × 0.25 model result (Fig. 3b) shows more vivid city plumes than from 2 × 2 model result (Fig. 3a). It also shows clearer vortex shape due to a typhoon near Kyusyu.

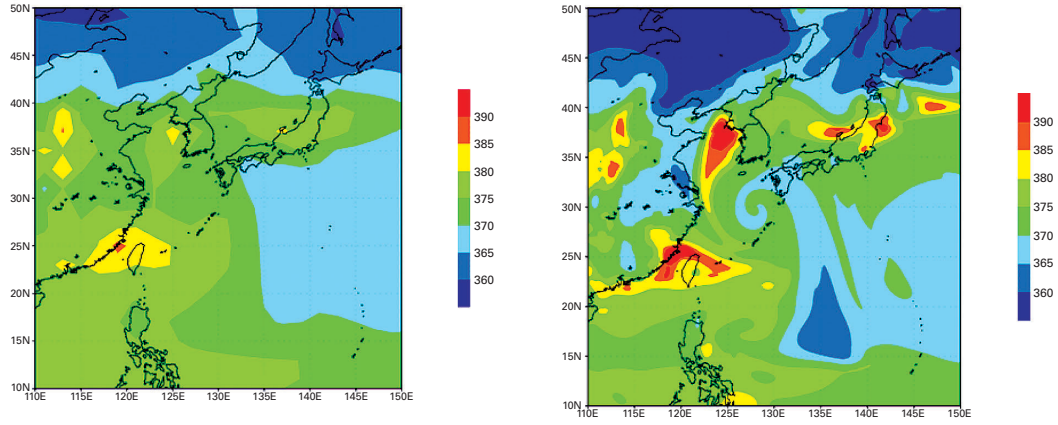

Fig. 3 Surface CO_2 distributions over East Asia on 30 August, 2002 at 0300 hour using (a) 2° × 2° resolution and (b) 0.25° × 0.25° resolution.

3. Carbon cycle analysis system using high-resolution time-dependent inversion using a JMA-CDTM model

The time-dependent inversion inter-comparison was prepared by using the off-line carbon dioxide transport model (JMA-CDTM) with 1.0 × 1.0 degree in horizontal resolution. By using the model, we have preceded two areas of our analysis system. First area is to develop the raw observational data screening approach using inverse model. Using this approach, we can enlarge the number of observational data for inversion method and we can estimate carbon dioxide (CO_2) flux history consistently in long period in accordance with the number of the observational sites.

Second area is to test the more partitioned area (from 22 to 64 regions) in time-dependent inversion. We have adopted the region division method by Patra et al., 2005. The 64 regions is one of the highest resolutions in current carbon-cycle research. We have estimated CO_2 monthly mean fluxes from 1993 to 2003 using time-dependent inversion. The observational data are from WMO/WDCGG. Figure 1 shows the analysis results.

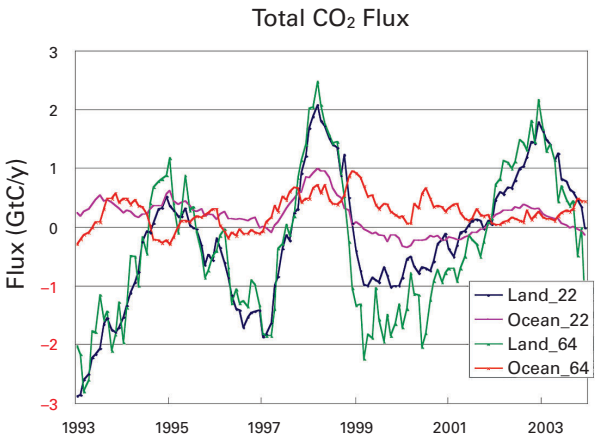

Fig. 4 Total CO_2 flux estimated by time-dependent inversion.

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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
プラビール・パトラ*1，石島健太郎*1，滝川　雅之*1，シャミール・マクシュートフ*2，
真木　貴史*3，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　国立環境研究所・地球環境研究センター
＊3　気象庁地球環境・海洋部

1. AGCMを用いた温室効果ガスの前進・逆モデリング

ECMWFまたはNCEP再解析データを利用してナッジングを行ったCCSR/NIES/FRCGC大気大循環モデル（AGCM）を用いて温室効果ガスおよび大気トレーサー（ラドン-222及びSF_6）の前進計算を行った。モデルの水平分解能は1 × 1度から2.8 × 1.8度まで、垂直分解能は15層から67層まで（対流圏-中間圏）で変化させた。67層バージョンのAGCMを化学反応による消失のある温室効果ガス（N_2O, CFC-12, CH_4）に対して適用したところ，地表におけるN_2Oの季節変化は成層圏−対流圏交換を考慮しないとよく説明できないことがわかった。本研究の結果は、温室効果ガスのシミュレーションにおいては対流圏と成層圏を一つの結合系として扱うことが必要であることを示唆している。

2．高分解能モデルによる二酸化炭素輸送のシミュレーション

人為起源CO_2排出について1 × 1度のインベントリーを人口統計地図を用いて25分メッシュに高解像度化し、低解像の陸域生態系モデル、海洋フラックスデータと結合した。異なった水平分解能で東アジアの地表面二酸化炭素分布を求めたところ、例えば都市部での二酸化炭素濃度は0.25 × 0.25度モデルにおいての方が2 × 2度モデルより顕著に高く現れることがわかった。

3. JMA-CDTM輸送モデルを用いた高分解能時間依存逆モデルによる炭素循環解析

気象庁のオフライン二酸化炭素輸送モデル（JMA-CDTM）を1 × 1度の水平分解能で走らせ、1993年から2003年の月平均CO_2フラックスの推定がなされた。得たれたフラックスについて既存の文献値との比較を行い、矛盾がないことを確認した。

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