Global tracer transport model analysis of the methane distribution in the atmosphere.

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1. Introduction.

Our understanding of the global cycles of greenhouse gases should be improved for drawing reliable future projections. Methane flux to the atmosphere is believed to be important contribution to global radiation budget of the Earth and especially to the global warming. The origin and distribution of the methane flux to atmosphere are intensively studied.

2. Objective.

Observational data on the concentrations of the greenhouse gases provide information on the concentration distribution and time variation which can be used for determination of the regional and local sources and sinks of greenhouse gases. Global tracer transport models are used for the model synthesis studies (*Fung, 1990*) and inverse problem solution (*Hartley, 1993*). Those models are generally based on GCM climate and wind or observationally adjusted global analysis data (*Taylor, 1991*). Using the GCM data for transport calculation is technically more convenient as long as large amount of data is produced on site with high temporal and spatial resolution and it is dynamically consistent. Model validation studies show that models based on observed winds do not require additional diffusive transport in the tropical convergence zone and can predict realistic inter-hemispheric exchange rates (*Taguchi, 1993*).

The objective of this study is to investigate the relationship between the methane emission source distribution and the vertical and horizontal distribution of the methane concentration in the troposhere. Particular goal is to study the difference between the tracer concentration in the boundary layer and free troposhere that was observed in the airborne methane concentration measurements. The reason for that difference is that vertical mixing rates are quite different among free troposhere and the boundary layer. While typical mixing time within the boundary layer is about one day, it may become an order of magnitude larger above the top of the boundary layer. As a result, the emitted methane is "trapped" in the boundary layer if the transport between the boundary layer and free troposhere is slow. This situation is limited to clear sky conditions when the transport by cumulous clouds is not present. Fig. 1 represents a vertical profile of methane concentration observed over Siberian lowlands in 1992 (*Uchiyama, 1993*). Observed concentration drop in the interface between the boundary layer and free troposhere is about 50 ppbv.

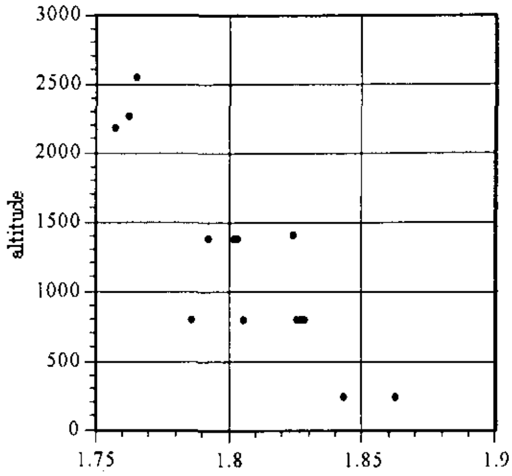

Fig. 1. Vertical methane concentration profile 18/07/92, 9am, (59N, 68E)

3. Model.

A global tracer transport model used in this study was developed in NIES for numerical simulations of the greenhouse gas distribution in the atmosphere. Model is based on *p*-σ vertical coordinate system, having 7 horizontal constant σ layers. Pressure on each that surface is proportional to the surface pressure. A transport equation is written as follows:

$$\frac{\partial p_s c}{\partial t} = \frac{\partial p_s c u}{R\cos\theta\partial\varphi} + \frac{\partial p_s c v\cos\theta}{R\cos\theta\partial\theta} + \frac{\partial p_s c\dot{\sigma}}{\partial\sigma} + S \quad (1)$$

Here: c - tracer mass fraction, p_s - surface pressure, R - Earth radius, $u, v, \dot{\sigma}$ - wind speed, φ, θ - longitude and latitude in radians, S -source-sink term.

Horizontal grid is rectangular 2.5 degree longitude-latitude grid, with larger longitude grid step near the pole. Variable horizontal step grid is necessary for the computationally effective transport calculation. Three-dimensional calculations with a high resolution model are consuming a lot of CPU time. Thus developing efficient algorithm and coding is a practically important issue. The time step for many advective transport algorithms is limited by the Courant-Frederics-Levy criteria: $\tau \le h/u$, where τ -time step, h - mesh size, u -maximum wind speed. In the regular high resolution grid the longitudinal step near the poles becomes too small compared to equatorial region, thus leading to a small model time step allowed. An introduction of a variable step size grid increases minimal h value resulting in the increase in the model performance. A sample of that grid structure is shown in Fig. 2.

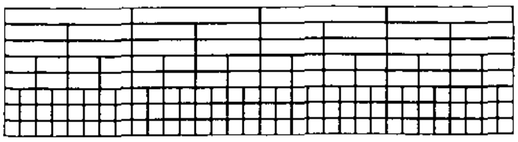

Fig. 2. Horizontal grid layout.

Wind, pressure and temperature data fields where adopted from ECMWF global analysis data with spatial resolution 2.5 degree longitude - latitude at 7 constant pressure levels (1000 - 100 mbar) and time resolution of 12 hours. Wind and temperature data are converted to terrain-following p-σ coordinate system using the surface elevation field data. Resulting wind field is not exactly mass-conservative in terms of Eq. 1, so the mass conservation adjustment had to be applied after transport calculations at each time step. The files of 1987 year analysis were used for calculations in this case.

Source term was derived from global emission inventories. One emission inventory relates the methane production to the net primary productivity (*Taylor, 1991*). For more accurate calculations of the methane profile over Siberian lowlands we use the wetland methane emissions (*Mattheus, 1987*). Sink due to atmospheric reactions is not calculated as long as it is slower than vertical mixing and is not important for calculating the concentration difference between the boundary layer and free troposphere.

4. Results and discussions.

Series of short term (several months long) calculations were conducted in order to see an effect of the large scale meteorological phenomena on the methane concentration variations in the boundary layer. According to the model calculations the areas of high concentrations in the lowest model levels correspond to the source areas and plumes that are transported downwind from the source areas. The plumes are often transported for several thousand kilometers downwind. Within a relatively short period of a one week after the start of a simulation the maximum values of a vertical concentration difference reach relatively stable level which varies in time by about 20%. Comparing the simulations with NPP-derived emission rate (Fig. 3) and separate wetland emission (Fig. 4), one can see that the former produces smaller emission rate and vertical concentration difference over Siberian lowlands area. Although the observations and meteorological data were not available for the same moment of time, the results show that maximum vertical concentration difference is related to the emission rates predicted by different emission inventories, this giving us a tool to evaluate the quality of the emission inventory using the observed vertical concentration profiles. It worth mentioning that tracer plumes corresponding to major source regions are well separated, thus giving an opportunity to treat each emission region separately

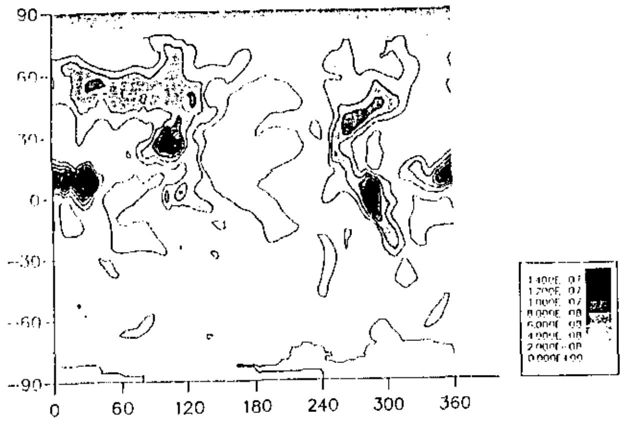

Fig. 3. Vertical concentration difference, NPP-related emission rate.

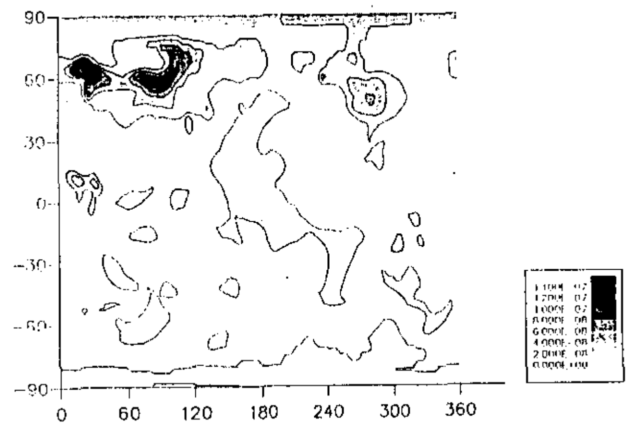

Fig. 4. Vertical concentration difference, wetland emission rate.

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