Study of the global material circulation by using General Circulation Model

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1. Introduction

Mass exchanges between mixing regions are meaningful and attractive issues in the investigation of global material circulation, such as exchanges between stratosphere and troposphere, northern hemisphere and southern hemisphere, higher latitudinal atmosphere and lower latitudinal atmosphere, as each level of the hierarchy of mixing regions. Main purposes in this paper are to construct methods to define borders dividing these mixing regions and assess the substantial mass flux through their borders in Lagrangian sense and to describe general circulation in the troposphere with the method.

2. Description of a New Method

A new method is proposed for assessing active mass flux in Lagrangian sense through an arbitrary geometrical surface. Consider a particle whose trajectory is known for a certain period, and a certain geometrical surface. We assume a certain standard time-scale T, which should be determined according to what time-scale we are concerned with in assessing the flux. We shall define a stay as a period of time during which a particle stays on one side of a surface. We shall define an active stay as one whose duration is longer than T, as mentioned in introduction. My method proposes to neglect intersections whose periods are shorter than T, because such short time-scale oscillating movement does not contribute to the global transport on time-scales longer than T. On these assumptions, active transits are defined as last intersections among ones that are temporally sandwiched by two active stays on each side.

3. Description of Models and Procedure of Analysis

An off-line tracer model to investigate trajectories of a large number of idealized particles which follow the atmospheric motion exactly, which uses stored data for wind and cumulus mass flux obtained by integrations of the Center for Climate System Research / the National Institute for Environmental Studies (CCSR/NIES) atmospheric general circulation model (GCM), was developed.

3.1. General Circulation Model

Description of The CCSR/NIES atmospheric GCM is presented in Numaguti et al (1997). The resolution for the GCM in this study was T42L20, where baroclinic waves are rather suitably resolved. After a preliminary integration for four years, the GCM was integrated for one year to obtain data for the tracer model. Horizontal velocities u, v, vertical velocity $d\sigma/dt$, temperature T, surface pressure P_s, and vertical mass flux by cumulus convection F_c were averaged over 4-hour intervals and the averages for each 4-hour interval were saved.

3.2. Tracer Model for Particle's Trajectory Calculation

Cumulus convection exerts a great influence on global atmospheric transport of materials since they are vertically diffused largely by convection. Therefore the tracer model considers the cumulus mass convection in addition to advection.

The interval of the time step of the trajectory calculation was 30 minutes. In each calculation time step, a judgment is first made as to whether or not a given particle is convected by the cumulus convection. When a particle is in a layer with a cumulus convection mass flux, whether or not a particle is captured by that cumulus convection depends on the sign of convergence of the cumulus mass flux (defined in each vertical boundary between layers) in the layer concerned. When the particle is judged to not be captured by convection by equation or when it is in a layer without a cumulus mass flux, the particle is advected. The velocity field $\boldsymbol{v}$ was linearly interpolated both in the horizontal and vertical directions from eight neighboring grids.

3.3. procedure of tracer calculation and application of the flux assessing method

Particles were initially located globally on 89 latitude circles from 88.0° north to 88.0° south at 2.0 degree intervals and in 18 vertical levels from $\sigma = 0.95$ to 0.10 at 0.05 intervals. In the longitudinal direction particles were located with equal longitudinal intervals on the circles in each latitude and height. The number of particles in a longitudinal direction was 360 × cos(latitude(in radians)). Then each one particle represents approximately equal mass, which is approximated as 1.2×10^{13} Kg.

A tracer calculation was done from January first to the end of March. The particles' position data, namely latitude, longitude, and pressure, are saved every six hours. On the basis of the position data,

the new method introduced in the previous section was applied to every transit of particles through surfaces of equal latitude for January, where latitudes are 82.5° north through 82.5° south at 5 degree intervals. Active fluxes of the particles through the surfaces are assessed by accumulating all selected active transits. Hereafter the flux of particles will be translated into the flux of mass in the discussion.

4. Results

Latitudinal distributions of mass flux as the sum of northward and southward fluxes through each latitude for 7 days show local evident minimums at both mid-latitudes, where maximums are shown for $T = 0$ days (Fig. 1). This means there is a potential barrier for global meridional transport in this time scale in each mid-latitude (Pierrehumbert and Yang 1993).

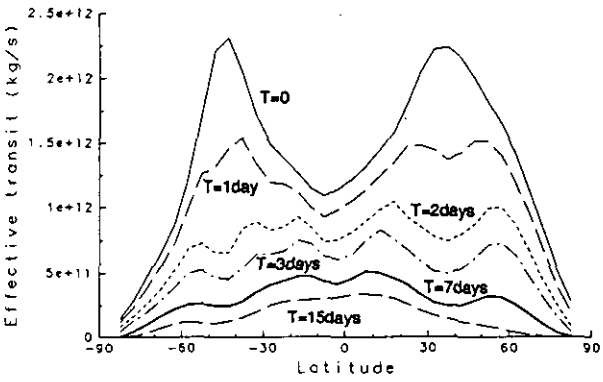

Figure. 1: Meridional distribution of meridional mass flux calculated by the scheme introduced in this paper (see text for details) for several time-scales of selection. *Northward and southward fluxes are summed and vertically integrated on each latitude.* Unit is Kg/s.

A latitude-height section of net meridional flux is discussed. The Eulerian meridional mean circulation is typical in that it consists of 3 cells in each hemisphere (Fig. 1 a). Although the stream function obtained from meridional mass flux obtained by the present scheme for $T = 0$ days (Fig. 2 b) should be the same as that derived from the Eulerian data (Fig. 2 a), Ferrel cells from the Lagrangian calculation for $T = 0$ days are weaker and confined to lower levels relative to those evaluated with the Eulerian data. The reason for this difference is particle's position data being calculated from 4-hour interval wind data and being saved at 4 hour intervals. Namely, much of the transport induced by motions with time-scales shorter than 4 hours are omitted from the flux calculated even in the $T = 0$ days analysis, and the difference between the Eulerian and lagrangian $T = 0$ days analyses (Fig. 2 a and b) corresponds to the fluxes with time-scales shorter than 4 hours. As the time-scale used in the Lagrangian analysis increases, the Ferrel cells at mid-latitudes become weak and restricted to close to the surface. Mid-latitude Ferrel cells disappear and a single cell structure exists in each hemisphere for 7 days (see Fig. 2 d). It should be noted that the contours for stream functions in mid-latitudes descend locally from above the upper atmosphere and ascend from near the surface. It is well known that a similar structure apparent in contours of stream functions obtained by the Transformed Eulerian Mean method.

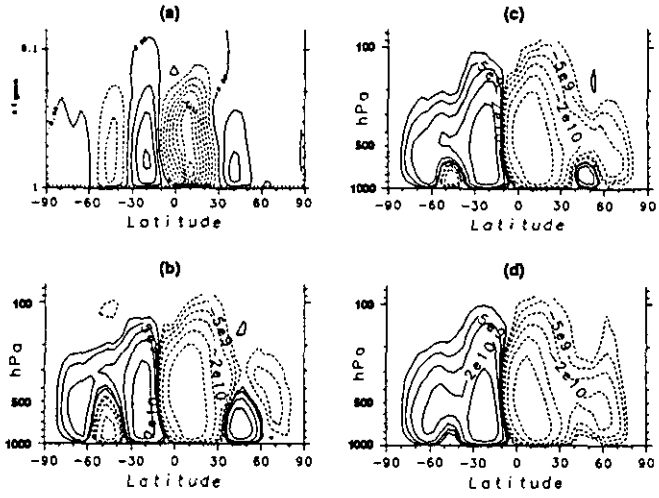

Figure 2: Meridional sections of stream functions for February. A stream function in figure (a) is obtained from meridional velocity data and density data from CCSR/NIES GCM. Stream functions in figures (b), (c), and (d) are obtained from meridional mass flux selected for of 0, 2, and 7 days, respectively.

5. Conclusion

A new scheme is proposed for abstracting the Lagrangian circulation which contributes to global transport from a general circulation. Analysis with the method showed the existence of potential barriers to global material meridional transport in mid-latitudes in addition to that near the ITCZ.

References

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