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MEAN-MERIDIONAL CIRCULATION OF THE POLAR STRATOSPHERE REPRODUCED IN A GCM

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Abstract: The lower-stratospheric circulation of a GCM is analyzed with the new TEM scheme in the pressure-isentrope hybrid vertical coordinate. The polar stratospheric downward mass flux in winter is found to be much larger in the NH than in the SH.

1. Introduction

The author developed a transformed Eulerian-mean method based on the pressure-isentrope hybrid vertical coordinate, which can provide us with a consistent view of transports of heat, angular momentum and material (IWASAKI, 1989, 1990). Using this scheme, the stratospheric mean-meridional circulation of an annual run of the NCAR CCM1 (T42, 12 levels) is studied. The details of the CCMl are described by WILLIAMSON *et al.* (1987).

The stratospheric mean-meridional circulation analyzed with the new scheme is similar to the diabatic circulation by MURGATROYD and SINGLETON (1961). Two direct cells similar to the Brewer-Dobson circulation are found in the lower stratosphere and they switch to a pole-pole circulation (from summer to winter hemispheres) with increasing altitude around the solstice.

Here, our attention is focused on asymmetric characteristics between the northern and southern hemispheres. In particular, the tropospheric-stratospheric mass exchange rate is compared with the previous estimation by HOLTON (1990).

2. Results and Discussion

Figure 1 shows time-latitude sections of the Eliassen-Palm (EP) flux divergence and mean-meridional flows at 54.1 hPa. The definitions of zonal means and the EP flux divergence and their computational procedures are given in IWASAKI (1989). In the NH high latitudes, the EP flux convergence is large in winter, while that in the SH high latitudes is weak all year round. Planetary waves seem to be more active in the NH due to the stronger zonal asymmetry of topographic and land-sea distributions. The meridional velocity, which roughly balances the EP flux divergence term in the extratropics, is larger in the NH winter than in the SH winter as shown in the lower panel. The convergences of the meridional flows cause vertical motions. Figure 2 shows the time-latitude section of mean-vertical velocity at 100 hPa. In the NH, descending flows become maximum in winter and rather uniform north of 30°N. On

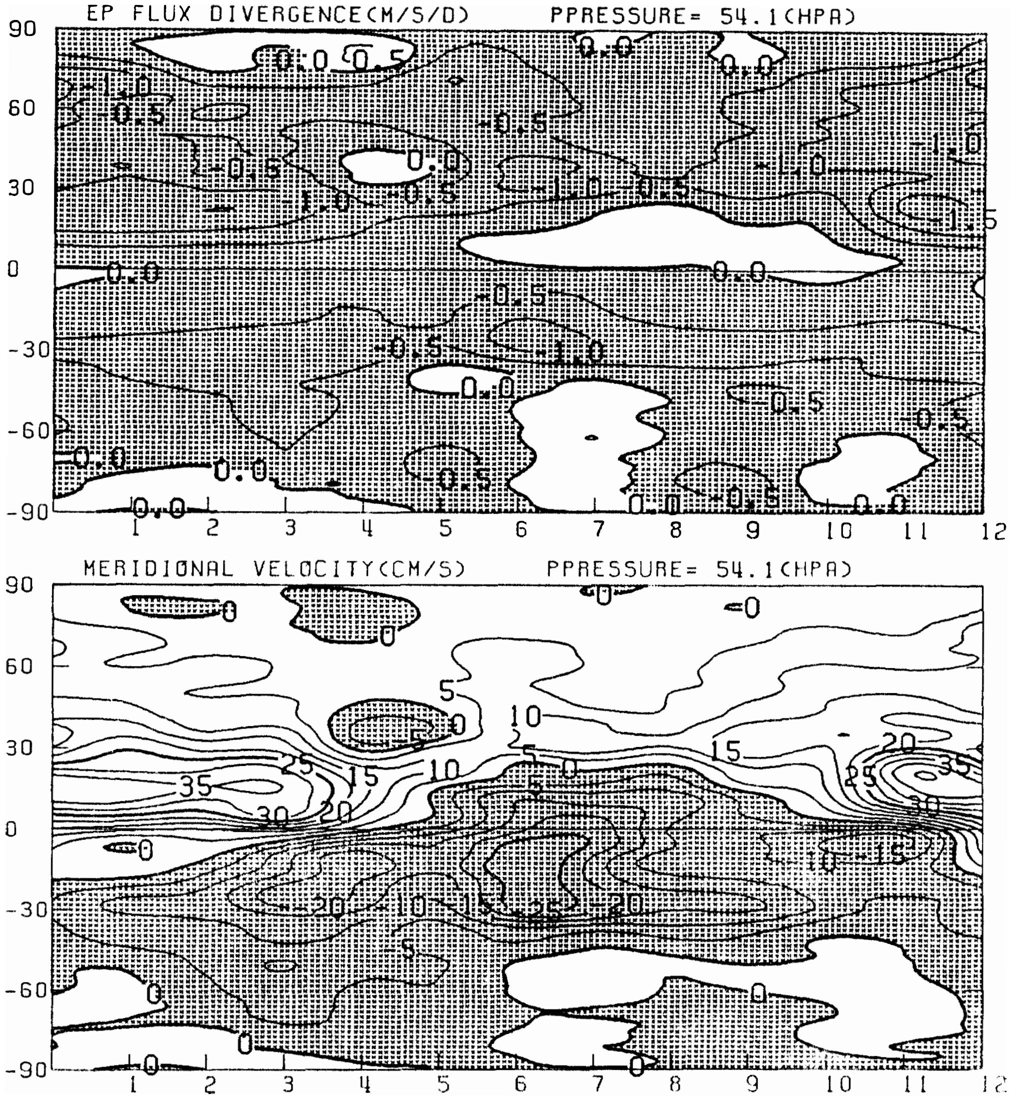

Fig. 1. Time (in month)-latitude sections of the Eliassen-Palm flux divergence (upper panel) and mean-meridional velocity (lower panel) at 54.1 hPa.

the other hand, in the SH, the main downward branch is located around mid-latitudes and provides adiabatic heating. Around the south pole, however, vertical motions are slow, especially in winter and spring. Approaching radiative equilibrium in winter, it is very cold within the vortex and temperature gradient between mid- and high latitudes becomes very large, which balances with strong polar night jetstream. Thus, weak wave-mean flow interactions in the SH high latitudes result in a strong circumpolar vortex in winter.

Finally, let us consider the global mass exchange rate between the stratosphere and troposphere through the total downward mass flux at 100 hPa (just below the tropical tropopause level). Figure 3 shows the downward mass flux at 100 hPa, where the air mass flux is integrated over negative portions of vertical velocity. Though in both hemispheres the downward mass flux becomes maximal in winter, it is larger in the NH than in the SH. Accordingly, the total exchange rate is maximized

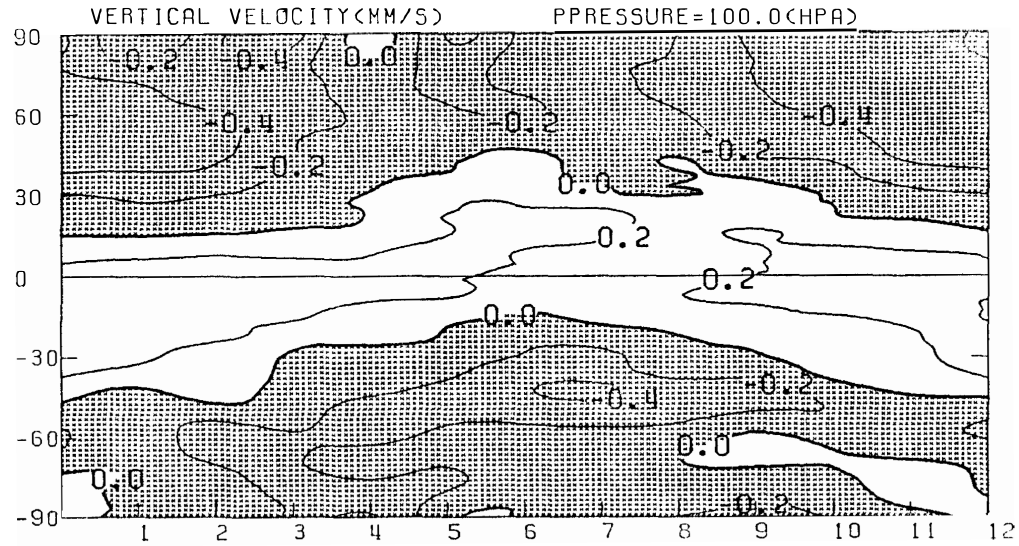

Fig. 2. Time (in month)-latitude section of mean-vertical velocity at 100 hPa, where the scale height of 7 km is used.

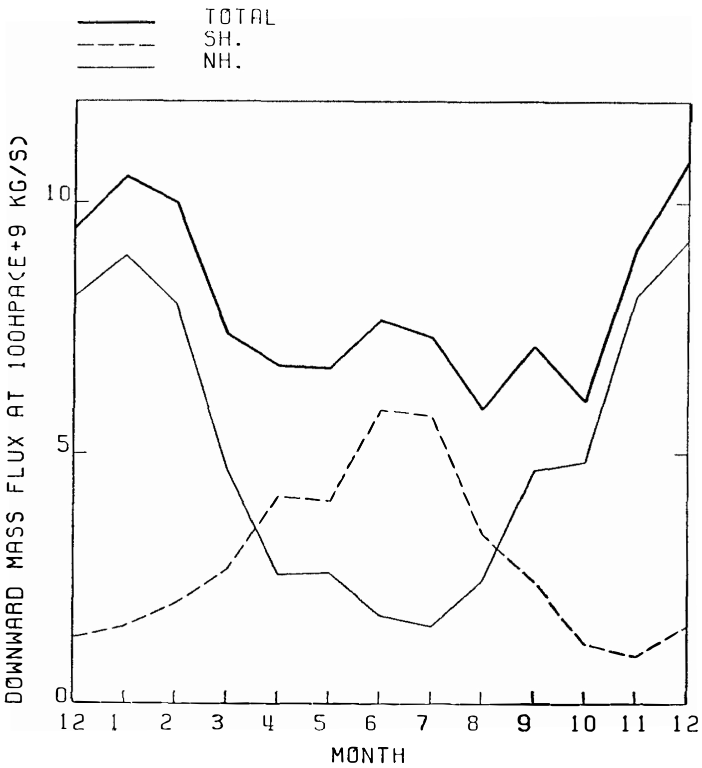

Fig. 3. Seasonal march of downward mass flux crossing over 100 hPa. Thin solid, broken and heavy solid lines indicate the NH, SH and total (NH+SH) mass flux, respectively.

in winter of the NH. Corresponding to the seasonal variation of total downward mass flux, the upward flux in the tropics minimizes the stratospheric temperature in winter of the NH, in agreement with observations. Thus, we can say that wave activity significantly controls even the global mass exchange rate between the stratosphere and troposphere.

The mass exchange rate has already been estimated according to the TEM analysis of climate data (HOLTON, 1990). The definition is a little different, that is, he regarded minimum and (maximum) values of streamfunctions at 100 hPa as total downward flux in the NH (SH), respectively. In principle, our method gives larger estimates when there exist areas of both positive and negative vertical velocity in the extratropics. The seasonal variation of downward mass flux analyzed here is very similar to that by HOLTON (1990), although our yearly-mean value is a little larger. The yearly-mean value should also be reconsidered in the future. The present estimation may be subject to finite difference errors, because the GCM analyzed here has only three layers above 100 hPa.

3. Concluding Remarks

The present analysis can reasonably depict asymmetry of mass circulation. In the NH winter, descending flows are uniformly strong north of 30°N. In contrast, in the SH winter, descending flows are centered around mid-latitudes and very weak within the circumpolar vortex. This asymmetry results in seasonal variation of global mass exchange rate between the troposphere and stratosphere. These facts can be interpreted in terms of the asymmetry of the wave activity between the two hemispheres, possibly coming from the excitation of ultra-long waves by the topography and land-sea distributions. According to BOVILLE and CHENG (1988), the 12-level version of the NCAR CCM1 underestimates the frequencies of stratospheric sudden warming. This means that the actual atmosphere is more asymmetric than the model atmosphere.

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