中間圏および下部熱圏の運動量収支とロスビー波と重力波の発生

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The momentum budget and generation of Rossby waves and gravity waves in the MLT region

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In the middle atmosphere, tides, gravity waves, and Rossby waves are dominant and play important roles. These waves drive the meridional circulation and form the thermal structure, which is partly much different from that expected through a radiative equilibrium, in particular, in the mesosphere and lower thermosphere (MLT) [Plumb, 2002]. However, the momentum budget of the MLT region has not thoroughly been examined. Tides have large amplitudes in the lower thermosphere. Gravity waves, which are mainly generated in the troposphere, become more important in the MLT region than in the troposphere and stratosphere. The wind and temperature fluctuation amplitudes of the gravity waves become large due to significantly low air density, and hence the gravity waves with large amplitudes are easily broken and deposit momentum largely affecting the climatology in the MLT region. The gravity wave forcing maintains a weak zonal wind layer around the mesopause and drive meridional circulation from the summer pole to winter pole. Rossby waves mainly break in the winter stratosphere and drive the Brewer-Dobson circulation. In the summer mesosphere, quasi-two day waves were frequently observed by satellites and by radars [e.g., Ern et al., 2013; Murphy et al., 2007]. The quasi-two day waves propagate westward and are considered to be the Rossby-gravity mode with (s, n) = (3, -3). These quasi-two day waves are likely excited by barotropic (BT) and/or baroclinic (BC) instabilities. Previous studies indicated that the BT/BC instabilities may be formed by gravity wave forcing in the mesosphere, although details are not explored yet. On the other hand, Sato and Nomoto [2015] showed that Rossby waves and gravity waves interplay in the middle atmosphere, and Rossby wave are radiated from the BT/BC instabilities induced by gravity wave forcing. However, the interplay between Rossby waves and gravity waves in the MLT region has not thoroughly been examined. In this study, the momentum budget, interplay and generation of Rossby waves and gravity waves in the MLT region are examined using data from satellite observations and from a whole atmosphere model (GAIA).

We show only the results from the GAIA data in this abstract. Even in the climatology, the magnitude of the potential vorticity (PV) on an isentropic surface is maximized in the low and middle latitudes of the summer mesosphere and in high latitudes of the winter mesosphere (Fig. 1a). The Eliassen-Palm (EP) flux associated with Rossby waves is strongly upward above the PV maximum in the mesosphere and reaches the lower thermosphere (at z ~ 110 km) in summer. The EP flux divergence is positive slightly poleward of the PV maximum where the latitudinal PV gradient (PVy) is anomalous (Fig. 1b). In the winter hemisphere, the EP flux is equatorward and upward, and the EP flux divergence is negative in the stratosphere and upper mesosphere. From a spectral analysis for this upward EPF region in summer, it is seen that westward propagating waves having a 1.8-day period and s = 2–4 are dominant. This feature is similar to that of quasi-two day waves reported by the previous observations. The feature that strong upward and equatorward EPF is distributed above the negative PVy region suggests that these waves are generated through the BT/BC instabilities. Moreover, it is shown that these PV maxima, namely, BT/BC instabilities are attributable to an increase in the static stability in the winter mesosphere and the increase in both static stability and relative vorticity in the summer mesosphere. Both increases in the static stability and that in the relative vorticity are caused by the parameterized gravity wave drag.

We also analyzed the characteristics of resolved gravity waves, EP flux in the summer mesosphere is downward and the EP flux divergence is positive (Fig. 2a). These features are mainly due to eastward propagating waves. Moreover, there is also significant westward wave contribution in the summer upper mesosphere and lower thermosphere (Fig. 2b). This result suggests that the gravity waves propagating westward are generated in the summer upper mesosphere and lower thermosphere. In the summer MLT region, because the mean zonal wind has strongly vertical shear, the occurrence frequency of Richardson number smaller than 1/4 is relatively large (Fig. 2c). To examine possible gravity wave radiation from this region, the existence of downward propagating waves is analyzed. The ratio of downward propagating gravity waves is large in the summer upper mesosphere (Fig. 2d). In particular, it is seen that westward waves mainly propagate downward in this region. This result shows that the gravity waves are generated due to the shear instability which caused by strong parameterized gravity wave forcing in the upper mesosphere.

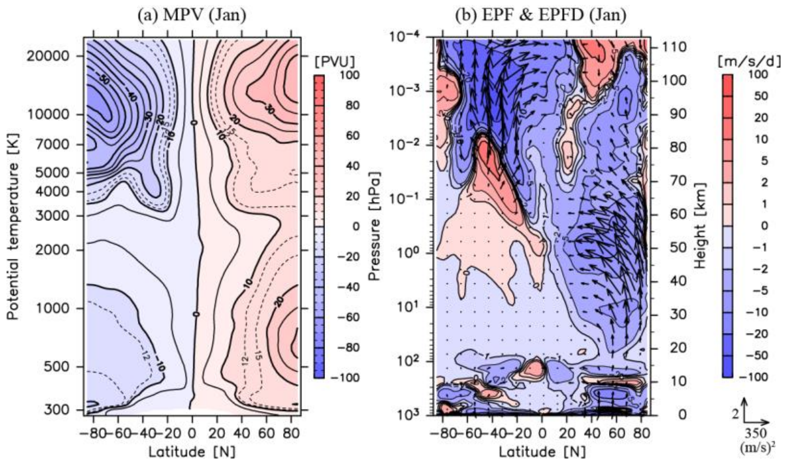

Figure 1. Latitude-height sections of climatology of (a) zonal mean modified PV (MPV) and (b) EP flux and EP flux divergence of Rossby wave component.

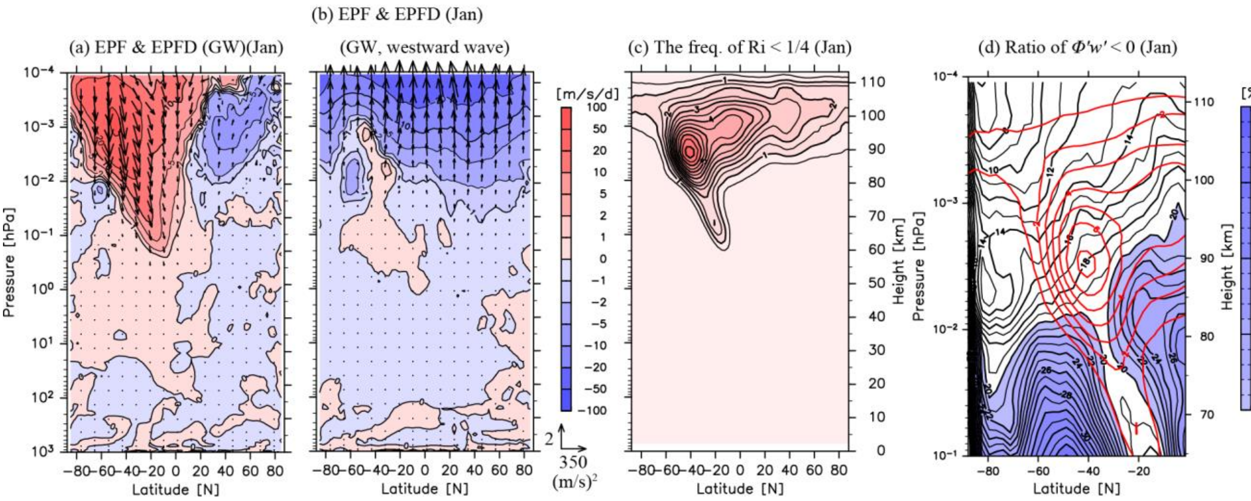

Figure 2. Latitude-height section of climatology of (a) EP flux and EP flux divergence of gravity wave component and (b) EP flux and EP flux divergence of westward propagating gravity wave component. (c) The frequency of Richardson number smaller than 1/4, and (d) the ratio of negative $\Phi' w'$ in Jan (black lines) and the frequency of Ri < 1/4 (red lines).

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