On the three-dimensional residual circulation and wave activity flux of the primitive equations

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Stratospheric ozone plays a significant role in the stratospheric radiation. The distribution of ozone and its two-dimensional transport in the meridional cross-sections have been evaluated by many studies using the residual mean meridional circulation of the Transformed Eulerian-Mean (TEM) equations. However, the TEM equations do not provide the three-dimensional view of the transport, so that the formulation of the three dimensional circulation is necessary.

There are several studies on a three-dimensional wave activity flux and residual circulation under the quasi-geostrophic assumption, which exclude small-scale perturbations such as gravity waves. Miyahara recently derived a three-dimensional wave activity flux and residual circulation applicable to gravity waves. However, his three-dimensional circulation does not satisfy the continuity equation. In addition, both the Eulerian-mean flow as well as the residual circulation appears in the advection term of the zonal momentum equation unlike the TEM equations.

This study formulates a new three-dimensional wave activity flux and residual circulation for the primitive equations based on Miyahara's theory. Moreover, the time mean tracer transport equation is derived using the derived three-dimensional residual circulation.

The obtained three-dimensional residual circulation satisfies the continuity equation, and all advection terms include the residual circulation only in the zonal momentum equation. Thus, the obtained formulae are regarded as a natural generalization of the TEM equations. A case study is made on the ozone transport using data from a Chemistry Climate Model to demonstrate the usefulness of the derived formulae.