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Global characteristics of vertical wavenumber spectra based on a high-resolution climate model

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It is well known by previous observational studies that, vertical wavenumber (m) spectra of horizontal wind and temperature fluctuations are proportional to m^{-t}, and t=3. The slope of spectra, t, is considered to be constant regardless of the season, geographical location and altitude range. Smith *et al*. derived the spectral amplitude theoretically assuming saturated gravity waves. Subsequent a lot of observational studies showed that this theory accords well with observations.

However, observations are usually made in limited geographical and vertical regions. First, there are many studies in the lower stratosphere, while there are a limited number of studies in mesosphere because observational data is insufficient at such high altitudes. Second, observational stations are not distributed uniformly. Thus, it is difficult to examine global characteristics of spectra only from observations. It is also shown in a few previous studies that slope and amplitude of the spectra slightly depend on the latitude. Furthermore, vertical wavenumber spectra of vertical velocity fluctuations have scarcely been examined so far because the observation of vertical velocity is very difficult. Thus, we examine global characteristic of vertical wavenumber spectra using data from a high-resolution general circulation model (GCM) which can resolve gravity waves explicitly without any gravity wave parameterizations. Seasonal and altitude dependence of the vertical wavenumber spectra is examined by analyzing data in two months of June and December in four height regions in the stratosphere and mesosphere.

First, vertical wavenumber spectra of GCM data (hereafter referred to as model spectra) compared with observed spectra, which are calculated using data from radiosonde observation campaign to scan the stratosphere meridionally over the middle Pacific in December 2001. It is shown that model and observational spectra accord well, assuring that the model data can be analyzed as a good surrogate of the real atmosphere. Characteristics of the model spectra are summarized as follows: Slopes of temperature spectra are generally close to t=3 but show significant dependence on the geographical location, season and altitude range. There are a maximum near the summer pole and weak maxima in the tropical region for the lower stratosphere. There are maxima at summer easterly and winter westerly jet regions in the lower mesosphere. Distributions of t values in December and June are almost symmetric about the equator. The characteristic vertical wavenumber of temperature spectra decrease with altitude, which is consistent with the theory by Smith *et al*. It is the theoretically expected that the relation between the spectral slopes for vertical wind (t_w) and temperature fluctuations (t_T) is $t_w=t_T+2$.However, the model spectra show that $t_w \geq t_T+2$ at most regions.

Second, several potential factors which control the shape of spectra are examined. There is positive correlation between the temperature variance and slope of temperature spectra in the upper stratosphere and lower mesosphere, which is consistent with the theory by Smith *et al*. However, the correlation in the lower stratosphere is low. The correlation between the spectral slope and the occurrence frequency of shear instability, which is one of the mechanisms for gravity wave saturation, is not high. These results suggest that the mechanism considered by Smith *et al*. do not act anywhere in the middle atmosphere. Instead, clear positive correlation is observed between the background horizontal wind speeds and the spectral slopes in particular in the lower mesosphere. A likely mechanism is that the intrinsic horizontal phase speeds of gravity waves become large in strong background wind conditions and hence the vertical wavenumbers become small following the dispersion relation.

Keywords: atmospheric gravity waves, vertical wavenumber spectra, high-resolution GCM