論文の内容の要旨

論文題目：A study of interannual and intraseasonal variation of atmospheric gravity waves in the stratosphere based on satellite data

（衛星観測データに基づく成層圏大気重力波の年々変動および季節内変動の研究）

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The recent development of high resolution observation instrument onboard satellites allows us to detect gravity waves in the broad wavenumber-frequency range that never before. Atmospheric Infrared Sounder (AIRS) is one of such satellite instruments which have the highest horizontal resolution of 13.5 km suitable to the studies of gravity waves in the stratosphere. Although the operational temperature product of AIRS has coarser resolution so far, the new temperature retrieval was made recently with original high horizontal resolution of AIRS. In this study, high resolution temperature data made from this new retrieval method for AIRS was used in order to clarify the characteristics of gravity waves at an altitude of 39 km in the middle stratosphere and to investigate their interannual and intraseasonal variations over nine years of 2003 to 2011.

AIRS is a nadir-view instrument and hence sensitive to gravity waves with longer vertical wavelengths than about 15 km. Because such gravity waves have large vertical group velocity, gravity wave packets may remain in an altitude range in a relatively short time and be localized in a limited horizontal region. Thus, the present study used the S-transform analysis, which is a wavelet analysis, in order to estimate the temperature fluctuation amplitudes, the horizontal wavelengths, and the direction of the horizontal wavenumber vector of gravity waves. First, to extract meaningful signals, the random noise originating from the temperature retrieval process was estimated in the location versus wavelength space using the S-transform analysis. The noise spectra are mainly distributed in the range of horizontal wavelengths shorter than about 70 km. Thus, the temperature perturbations with horizontal wavelengths longer than 70 km were analyzed as gravity waves in this study.

Second, the seasonal variation and latitudinal dependence of the zonal mean gravity wave amplitudes, horizontal wavelengths, and direction of the horizontal wavenumber vector are investigated. Gravity waves have large amplitudes in the winter high latitudes and in the summer subtropics. These peaks are likely due to the significant Doppler shift by strong mean wind with which gravity waves tend to have sufficiently long vertical wavelengths to be detected by AIRS. Such an effect is called the observational filter. This latitudinal distribution and time variation of observed gravity wave variance and its time series are consistent with previous studies using Microwave Limb Sounder (MLS) data which are also sensitive to long vertical-scale fluctuations. The horizontal wavelengths are large in the season and latitudes where gravity waves have large amplitudes. It is interesting that the mean meridional component of horizontal wavenumber vector near the polar night jet in the southern hemisphere is northward (southward) in latitudes higher (lower) than 60°S. This distribution implies that gravity waves propagate into the polar night jet axis. Although such gravity wave focusing into the polar night jet was suggested by a general circulation model study resolving gravity waves and several observational case studies on mountain waves using satellite data, this study first reported such gravity wave focusing in a climatological sense using global observational data.

The seasonal mean gravity wave amplitudes have a clear dependence on the longitude in the summer subtropics, although the mean zonal wind does not change much longitudinally. This longitudinal dependence of gravity waves is similar to that of precipitation as is consistent with previous studies. An interesting feature is that the gravity wave amplitude maxima around the South Pacific Convergence Zone (SPCZ) are located in slightly higher latitudes than the precipitation maxima by about 3°. Through theoretical considerations, it is shown that this latitudinal difference may be explained by three mechanisms; more vigorous excitation of gravity waves on the islands southward than over the ocean, the selective excitation of gravity waves propagating southward by convection in the wind shear, and the observational filter effect due to a slightly stronger background zonal wind at higher latitudes. The gravity wave refraction due to the meridional gradient of the zonal wind is not sufficiently large to explain the propagation by 3° latitude. The critical level filtering is expected to act gravity waves at higher latitudes more effectively hence it is not consistent with the fact that the maximum of gravity wave amplitudes is located at higher latitudes relative to the precipitation maxima. The meridional wind is too weak to advect gravity wave packets southward.

The year-to-year variation of gravity wave amplitudes is larger in the austral summer subtropics than in the boreal summer subtropics. Thus, the interannual variation of gravity wave amplitudes in the austral summer subtropics is investigated using a regression of the DJF-mean time series of gravity wave amplitudes and of precipitation to that of sea surface temperature in the NINO.3 region. Precipitation area around the SPCZ shifts southeastward (northwestward) in the El Niño (La Niña) phase. Gravity wave amplitudes exhibit similar change depending on the ENSO phase. Moreover, it is shown that the interannual variations of the regional mean precipitation in the equatorial central South Pacific and to the east of the SPCZ are similar to the NINO.3 time series, while that to the west of the SPCZ shows the change similar to NINO.3. Mean gravity waves exhibit a similar interannual variation to the precipitation in all of three regions. It is also shown that such interannual variation of gravity wave amplitudes depending on the region does not come from the observational filter effect. It should be emphasized that there are no previous studies showing a clear relation of the interannual variation of gravity wave amplitudes to the ENSO.

Next, the intraseasonal variation of gravity wave amplitudes is examined. Gravity wave amplitude averaged over the latitudes of 0°S to 20°S is compared with the precipitation and the zonal wind at 100 hPa corresponding to the tropopause in the longitude-time cross section. It is clear that large gravity wave amplitudes are observed in association with eastward migrating precipitation due to the Madden-Julian Oscillation. Moreover, it is also shown that gravity wave amplitudes are weak in the region where the zonal wind is eastward at the tropopause level. Thus, gravity wave amplitudes in the middle stratosphere are controlled by the precipitation as their sources and by the zonal wind at the tropopause causing critical level filtering against vertical propagation.

These results strongly indicate that the momentum transport to the summer mesosphere by gravity waves has significant interannual and intraseasonal variations depending on the convective activity and the zonal wind at the tropopause in the austral summer subtropics.