“Vertical and Interhemispheric Coupling in the Middle Atmosphere”

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The neutral atmosphere, which is characterized by a constant mixing ratio, extends to a height of about 100 km above the earth’s surface. The layer above the troposphere, which is the lowest atmospheric region, is called the middle atmosphere. The bulk of the middle atmosphere consists of two main layers, the stratosphere and the mesosphere, which are distinguished on the basis of temperature stratification. Part of the thermal structure of the middle atmosphere is far different from the state of radiative equilibrium. This peculiar structure is maintained through Lagrangian mean circulation driven by momentum and heat transport by Rossby waves and gravity waves. The recent development of satellite observation technology has allowed us to examine the middle atmosphere, including the whole mesosphere, and several interesting and spectacular phenomena have been discovered.

This lecture will focus on two striking phenomena initiated by a well-known event called sudden stratospheric warming (SSW), in which the polar winter temperature rises by tens of degrees in a few days. One of these resulting phenomena is a significant warming of the upper mesosphere of the summer hemisphere, which develops almost simultaneously with or slightly after the SSW of the winter hemisphere. The other one is the disappearance and subsequent re-formation of the stratopause at an unusually high level, which sometimes occurs after a strong SSW event.

Because of a lack of solar radiation, the stratopause, which is defined as the region of temperature maximum at the top of the stratosphere, does not arise through ozone heating in the polar winter. Instead, the polar winter stratopause is maintained by adiabatic heating associated with a downward branch of the Lagrangian mean flow in the mesosphere driven by gravity waves originating mainly from the troposphere. In contrast, SSW is caused by an enhanced downward branch of the Lagrangian mean flow generated via the penetration of strong Rossby waves from the troposphere. The modified temperature field in the stratosphere changes the horizontal wind field in the thermal wind balance, which significantly affects the upward propagation of gravity waves in the stratosphere. The mesospheric circulation and hence the polar winter stratopause are also modified by the modulated gravity waves. The modification sometimes extends to the other (i.e., the summer) hemisphere.

The overall scenario has been discussed in consideration of the processes described above. However, the gravity waves have such a small spatial scale that observational evidence of them is hard to obtain. The timings of the elevation of the stratopause and of the interhemispheric coupling are not constant, and the reason is not clear. Moreover, recent studies indicate that gravity waves do not always behave passively toward large-scale Rossby waves in the middle atmosphere. The interplay of Rossby waves and gravity waves may be a clue for developing a quantitative understanding of these phenomena.

International observation campaigns have been performed in recent years using mesosphere–stratosphere–troposphere (MST), meteor, and medium-frequency (MF) radars; lidars; and imagers that can capture the modulation of gravity waves that occurs when an Arctic SSW event is initiated. These observational results will be interpreted using the results of simulations performed with high-resolution general circulation models. This is an international project called The Interhemispheric Coupling Study by Observations and Modelling (ICSOM, PI: KS). The dynamics of vertical and interhemispheric coupling through the middle atmosphere and the recent progress on this issue will be reviewed.