

オゾン回復と二酸化炭素増加に対する中層大気の力学的応答 On the dynamical responses in the middle atmosphere to ozone recovery and CO₂ increase

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Observational evidences have shown the stratospheric ozone decrease in the past decades. A preceding paper to the present study, Smith et al. [2010], examined the response of the mesospheric circulation and temperature to the past ozone loss using data from the Whole Atmosphere Community Climate Model (WACCM) developed by National Center for Atmospheric Research. They found a strong negative trend in the strength of the mesospheric residual flow driven by gravity waves in the Southern Hemisphere (SH) during early summer. The resultant temperature trend through the adiabatic process is positive in the polar mesosphere and negative in the lower thermosphere. The mechanism can be explained as follows: Ozone depletion leads a cooling trend in the lower stratosphere. The increase of positive temperature gradient is accompanied by westerly wind even in the early summer. The early summer westerly wind reduces the net eastward gravity wave drag in the mesosphere by wave filtering in the lower stratosphere. The residual flow from the summer to winter hemispheres is then weakened to modify the temperature responses around the polar mesopause.

On the other hand, many chemistry-climate models have simulated the disappearance of the ozone hole by the mid-21st century. One of the purposes of the present study is to investigate how the dynamical response changes in the ozone recovery period in the WACCM simulation for the 21st century. We have investigated linear trends of temperature, zonal wind, and residual circulation in the early SH summer in the period of 2005-2050 simulated by WACCM. Antarctic ozone recovery leads to temperature increase in early summer in the lower stratosphere which weakens westerly winds in the stratosphere. This mean zonal wind change modifies the filtering of gravity waves propagating into the mesosphere. The penetrating gravity waves accelerate the mesospheric equatorward flow which is followed by the accelerated upwelling below the mesopause in the southern polar region. These results support the mechanism of Smith et al. [2010].

In addition to ozone changes, the CO₂ emission scenarios are included in the WACCM simulation. The CO₂ variation also influences the background temperature fields by modification of radiation balance. We compared three simulations with different CO₂ scenarios to examine dynamical responses to them in the period of 2050-2100. An interesting feature appears around the winter stratopause. In the simulations, the winter polar stratosphere has warming trend against our intuition for CO₂ increase which has cooling effect on the stratosphere. The warming trend is caused by the acceleration trend of the Brewer-Dobson circulation due to the increasing trend of the amount of the E-P flux convergence in the upper stratosphere. At the same time, the westerly in the polar stratosphere is weaker in the future through the thermal wind balance. The wind profile filters the gravity wave propagation into the mesosphere. As a result of reduction of the net westward gravity wave drag, the mesospheric meridional circulation is decelerated. The winter polar mesospheric temperature then decreases by the decrease of adiabatic heating due to weakened downwelling. Combination of the cooling in the polar mesosphere and warming in the polar stratosphere lowers the stratopause height defined as the vertical temperature maximum.

キーワード: 残差循環, 大気波動, 将来予測

Keywords: residual circulation, atmospheric waves, future prediction