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Radiative effects of ozone waves on the Northern Hemisphere polar vortex and its modulation by the QBO

Vered Silverman (1), Nili Harnik (1), Katja Matthes (2), Sandro W. Lubis (3), and Sebastian Wahl (2)

(1) Department of Geophysics, Tel Aviv University, Tel Aviv, Israel (vered.silverman@gmail.com), (2) GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany, (3) Department of the Geophysical Sciences, The University of Chicago, USA

The radiative effects induced by the zonally asymmetric part of the ozone field have been shown to significantly change the temperature of the Arctic winter polar cap, and correspondingly the strength of the polar vortex. We aim to understand the physical processes by which the radiative effects of ozone waves can significantly influence the winter polar vortex. We use the NCAR Whole Atmosphere Community Climate Model run with 1960's ozone depleting substances and green house gases. We find a significant effect on the mid-winter polar vortex only when examining the QBO phases separately. Moreover, the emergence of a midlatitude QBO signal (the Holton-Tan effect) is delayed by one to two months when radiative ozone wave effects are removed. The influence of ozone waves on the winter polar vortex, via their modulation of shortwave heating is not obvious, given that shortwave heating is largest during fall, when planetary stratospheric waves are relatively weak. We use a combined analysis of zonal wave 1 amplitudes of temperature perturbations using explicit temperature time tendency terms, alongside a synoptic analysis of upward planetary wave pulses. We find the direct radiative effect of ozone waves on temperature waves, and consequently on the zonal mean zonal wind, is most significant during early fall. Subsequently, we are able to show the chain of events that leads from an early fall direct radiative effect on the upward propagating planetary waves when they are still very weak, to a mid-winter polar vortex modulation. The resulting mean-flow differences accumulate during fall and early winter, after which they get amplified through wave-mean flow feedbacks. We find that the evolution of these early-winter upward planetary wave pulses and their induced stratospheric zonal mean flow deceleration is qualitatively different between the QBO phases, providing a new mechanistic view of the extratropical QBO signal. We further show how these differences result in an opposite effect of the radiative ozone wave perturbations on the mean flow deceleration for east and west QBO phases.