Propagation of gravity waves and its effects on pseudomomentum flux in a sudden stratospheric warming event

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Effects of realistic propagation of gravity waves (GWs) on distribution of GW pseudomomentum fluxes are explored using a global ray-tracing model for the 2009 sudden stratospheric warming (SSW) event. Four-dimensional (4D; $x$-$z$ and $t$) and two-dimensional (2D; $z$ and $t$) results are compared for various parameterized pseudomomentum fluxes. In ray-tracing equations, refraction due to horizontal wind shear and curvature effects are found important and comparable to one another in magnitude. In the 4D, westward pseudomomentum fluxes are enhanced in the upper troposphere and northern stratosphere due to refraction and curvature effects around fluctuating jet flows. In the northern polar upper mesosphere and lower thermosphere, eastward pseudomomentum fluxes are increased in the 4D. GWs are found to propagate more to the upper atmosphere in the 4D, since horizontal propagation and change in wave numbers due to refraction and curvature effects can make it more possible that GWs elude critical level filtering and saturation in the lower atmosphere. GW focusing effects occur around jet cores, and ray-tube effects appear where the polar stratospheric jets vary substantially in space and time. Enhancement of the structure of zonal wavenumber 2 in pseudomomentum fluxes in the middle stratosphere begins from the early stage of the SSW evolution. An increase in pseudomomentum fluxes in the upper atmosphere is present even after the onset in the 4D. Significantly enhanced pseudomomentum fluxes, when the polar vortex is disturbed, are related to GWs with small intrinsic group velocity (wave capture), and they would change nonlocally nearby large-scale vortex structures without substantially changing local mean flows.