A simple parameterization of the effects of secondary GWs due to orographic primary GWs and its impacts in the upper mesosphere of whole atmosphere models

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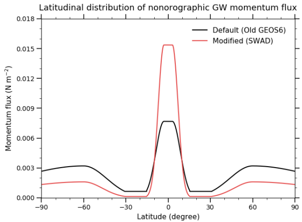
Introduction

- High-top models' common discrepancies against OBS
  - Large easterly biases in the winter polar upper mesosphere (Dempsey et al., 2021; Harvey et al., 2022; Hindley et al., 2022).
  - Biases are not fully corrected by OBS DA, and they are often attributed to GW parameterizations (GWPs) in high-top models (McCormack et al., 2022).
  - The easterly biases do not seem to be present in models where orographic secondary GWs (OSGWs) are explicitly simulated (Becker and Vadas, 2018).
  - Orographic primary GWs (OPGWs) are much larger in amplitude than non-orographic primary GWs (NOPGWs), and thus OSGWs may have major impacts in the polar mesosphere compared to nonorographic secondary GWs (NOSGWs).
  - A simple columnar parameterization of the effects of OSGWs are proposed and its impacts in the mesosphere are presented using mechanistic model and WACCM6.

Models and GWPs

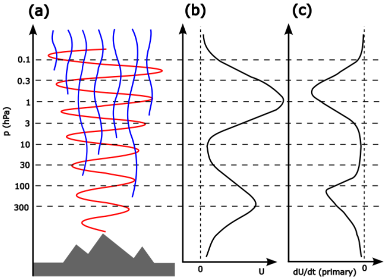
- Models
  - Mechanistic model: System for Whole Atmosphere Dynamics Researches (SWAD, Song 2023)
    - CAM3 dynamical core (Williamson and Olson, 1994), Held-Suarez-type radiation, Lindzen-type GWP (NASA GEOS5-6) for OPGWs (McFarlane, 1987) and NOPGWs (see below), molecular diffusion.
    - 20-yr perpetual JAN & JUL simulations at T42 resolution

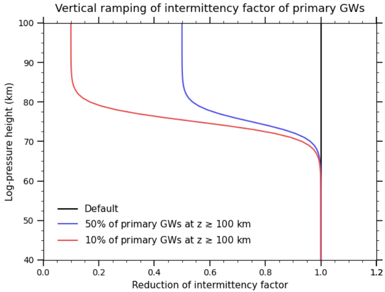


  - SC-WACCM6 (CAM6 physics) in CESM 2.2.0 (Compset: FWsc2000climo)
    - Lindzen-type GWP for mesoscale mountain ridges (Scinocca and McFarlane, 2000), fronts and convection.
    - 10-yr simulations at 2-deg resolution

Secondary GWP I

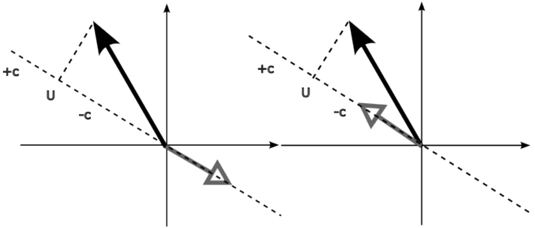
- Orographic secondary GWD
  - Launched at levels above orographic primary GWs produce momentum forcing.
  - Seven source levels from 300–0.1 hPa
  - Vertical reduction (ramping) of intermittency factor for primary orographic and nonorographic GWDs.
    - 50% or 10% of original value (0.125) above $z = 75$ km
    - Justification needed, and discussed later





Secondary GWP II

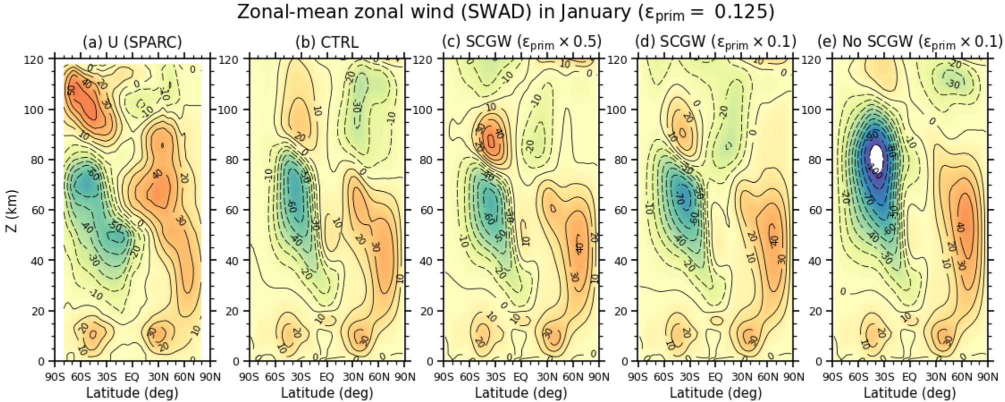
- Orographic secondary GWD
  - Two-wave scheme: Intrinsic phase speeds ($\hat{c}$) of orographic secondary GWs are ± 60 m s^{-1} (ground-based phase speed $= U \pm \hat{c}$) in the sense of the orographic primary GWD.
    - Consistent with $\lambda_z \approx$ 18–25 km from McMurdo OBS and modeling results (Vadas and Becker, 2018).
    - Filled arrow: Horizontal wind, Hollow arrow: GWD due to OPGWs.



  - Momentum flux magnitude for each is about 5% of the maximum of nonorographic GW flux in SWAD (0.0064 N m$^{-2}\times$ 5% $=$ 0.00032 N m^{-2} at each source level).

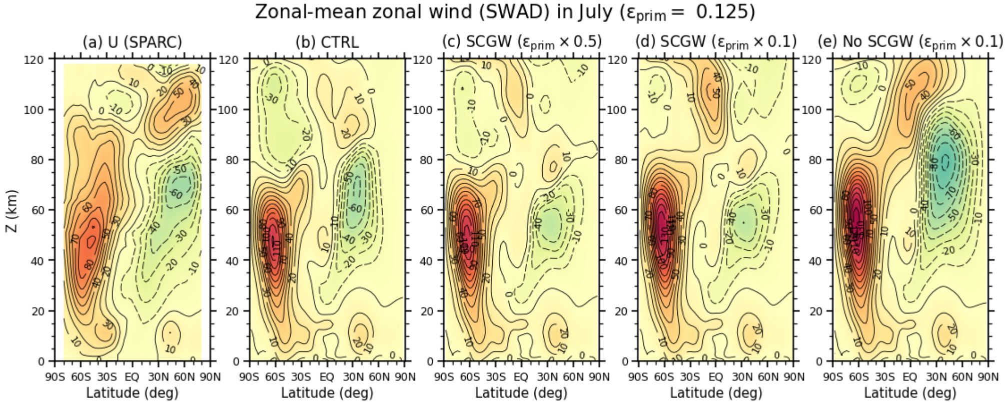
Results I

- Zonal-mean zonal wind in January (SWAD)
  - (a) SPARC (Ref Clim), (b) CTRL, (c) $\epsilon = 50\%$ above $z > 75$ km, (d) $\epsilon = 10\%$ above $z > 75$ km, and (e) No orographic secondary GWD for $\epsilon = 10\%$ above $z > 75$ km



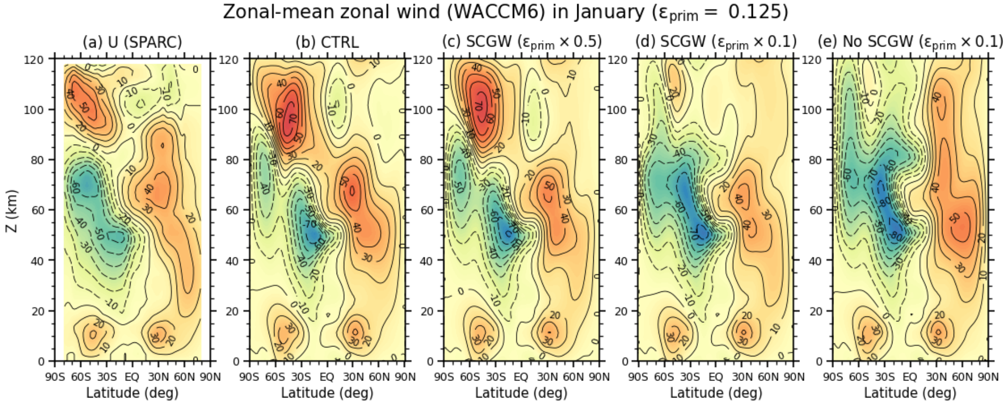
Results II

- Zonal-mean zonal wind in July (SWAD)
  - (a) SPARC (Ref Clim), (b) CTRL, (c) $\epsilon = 50\%$ above $z > 75$ km, (d) $\epsilon = 10\%$ above $z > 75$ km, and (e) No orographic secondary GWD for $\epsilon = 10\%$ above $z > 75$ km



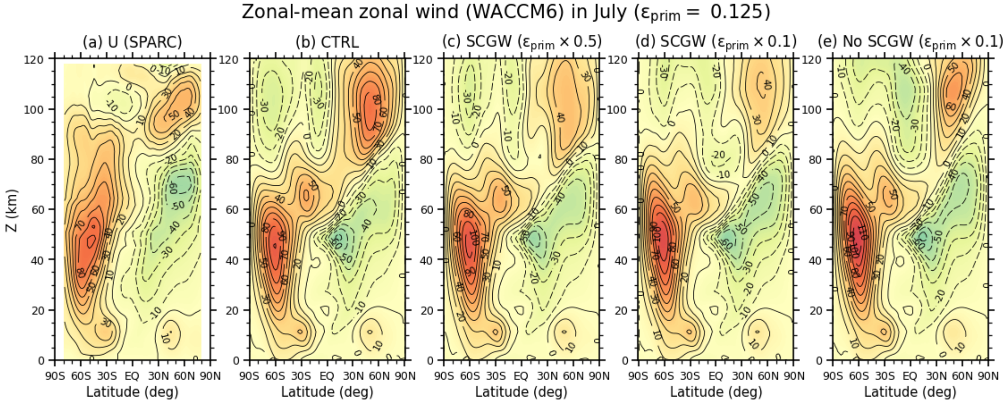
Results III

- Zonal-mean zonal wind in January (SC-WACCM6)
  - (a) SPARC (Ref Clim), (b) CTRL, (c) $\epsilon = 50\%$ above $z > 75$ km, (d) $\epsilon = 10\%$ above $z > 75$ km, and (e) No orographic secondary GWD for $\epsilon = 10\%$ above $z > 75$ km



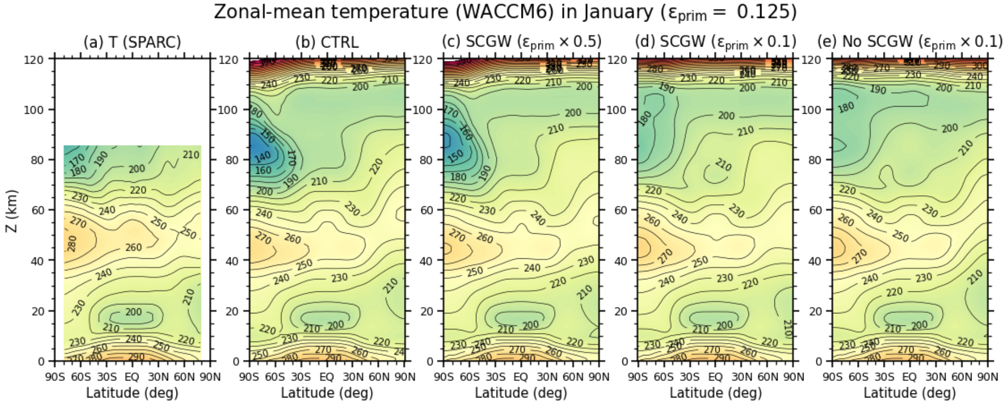
Results IV

- Zonal-mean zonal wind in July (SC-WACCM6)
  - (a) SPARC (Ref Clim), (b) CTRL, (c) $\epsilon = 50\%$ above $z > 75$ km, (d) $\epsilon = 10\%$ above $z > 75$ km, and (e) No orographic secondary GWD for $\epsilon = 10\%$ above $z > 75$ km



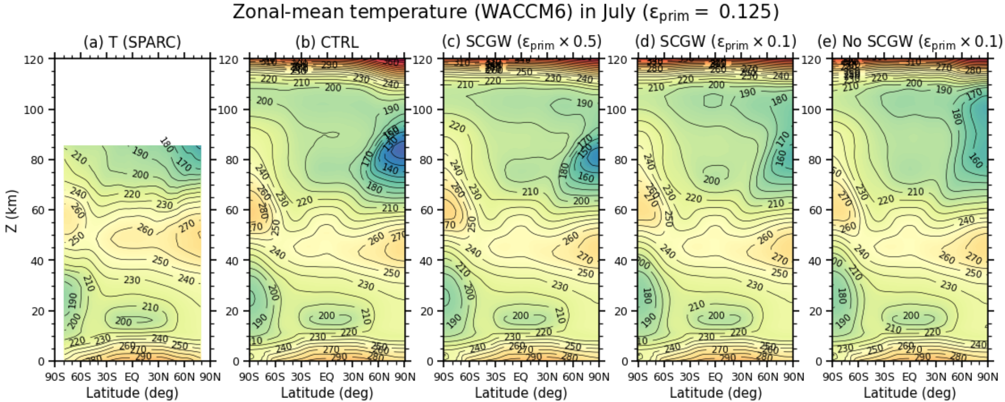
Results V

- Zonal-mean temperature in January (SC-WACCM6)
  - (a) SPARC (Ref Clim), (b) CTRL, (c) $\epsilon = 50\%$ above $z > 75$ km, (d) $\epsilon = 10\%$ above $z > 75$ km, and (e) No orographic secondary GWD for $\epsilon = 10\%$ above $z > 75$ km



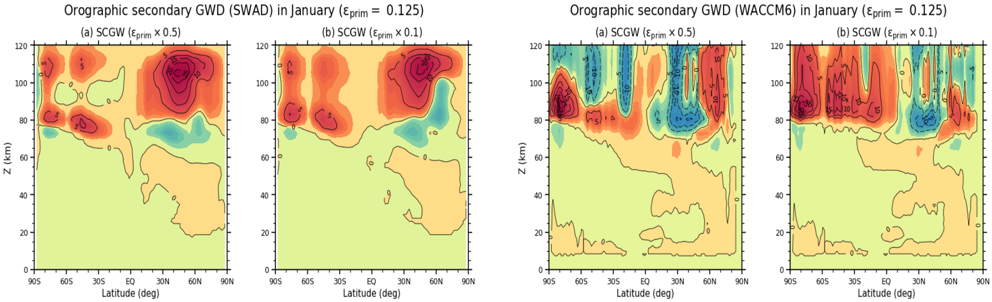
Results VI

- Zonal-mean temperature wind in July (SC-WACCM6)
  - (a) SPARC (Ref Clim), (b) CTRL, (c) $\epsilon = 50\%$ above $z > 75$ km, (d) $\epsilon = 10\%$ above $z > 75$ km, and (e) No orographic secondary GWD for $\epsilon = 10\%$ above $z > 75$ km



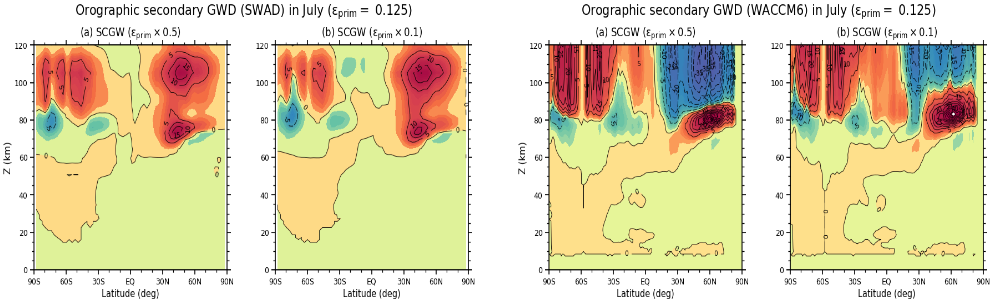
Results VII

- Zonal-mean OSGWD in January (SWAD and SC-WACCM6)
  - (a) $\epsilon = 50\%$ above $z > 75$ km, (b) $\epsilon = 10\%$ above $z > 75$ km
  - Maximum of $|\mathrm{GWD_{OSGW}}|$ is about 20 m s^{-1}/day



Results VIII

- Zonal-mean OSGWD in July (SWAD and SC-WACCM6)
  - (a) $\epsilon = 50\%$ above $z > 75$ km, (b) $\epsilon = 10\%$ above $z > 75$ km
  - Maximum of $|\mathrm{GWD_{OSGW}}|$ is about 20 m s^{-1}/day



Summary

- Simple parameterization of OSGWs
  - A simple parameterization of OSGWs is presented and tested in mechanistic model and full GCMs (SWAD and SC-WACCM6).
  - OSGWs can help reduce the eaterly biases in the upper mesosphere above the winter polar vortex.
  - OSGWs can make cold summer polar mesopause warmer: Weaker pole-to-pole circulation
  - Impacts may depend on the vertical ramping of the intermittency factors for primary GWs that needs justification.
    - Strong turbulent diffusion in the mid-to-upper mesosphere
    - Horizontal spread (dispersion) of primary GWs generated by point sources in the troposphere
  - Justification is needed, but combination of the ramping and parameterization for OSGWs can have some good impacts in the MLT regions.
- Future works: Impacts in residual circulations, eddy diffusion, planetary and tides in WACCM and WACCM-X.

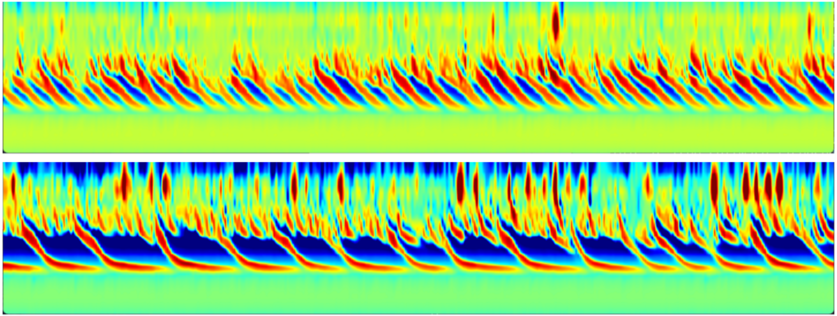
End of presentation

Thank you for attention

Backup I

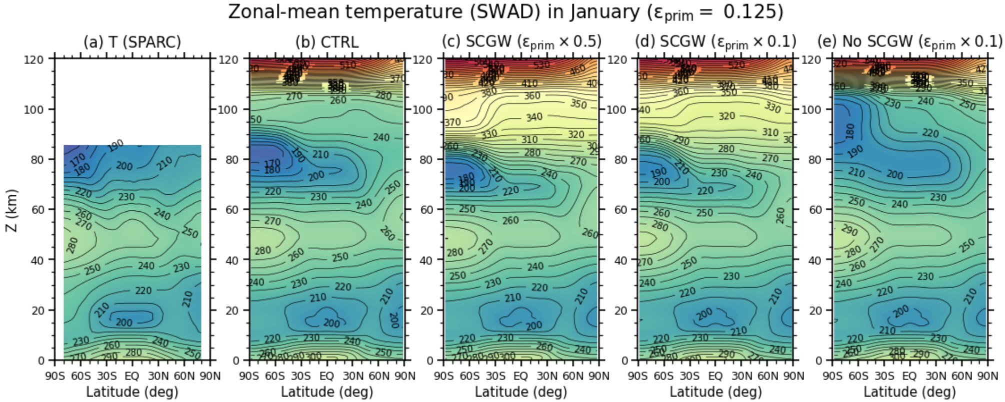
- Quasi-biennial oscillation in SWAD
  - Increase of QBO period due to eastward zonal momentum forcing in the equatorial lower stratosphere (12 month → 25 month (max))

$$\frac{\partial u}{\partial t} = \cdots + 0.242 \mathrm{~m~s^{-1}~day^{-1}} \exp[-(\phi^2/15^2)] \exp[-(z-25)^2/7^2]$$



Backup II

- Zonal-mean temperature in January (SWAD)
  - (a) SPARC (Ref Clim), (b) CTRL, (c) $\epsilon = 50\%$ above $z > 75$ km, (d) $\epsilon = 10\%$ above $z > 75$ km, and (e) No orographic secondary GWD for $\epsilon = 10\%$ above $z > 75$ km



Backup III

- Zonal-mean temperature in July (SWAD)
  - (a) SPARC (Ref Clim), (b) CTRL, (c) $\epsilon = 50\%$ above $z > 75$ km, (d) $\epsilon = 10\%$ above $z > 75$ km, and (e) No orographic secondary GWD for $\epsilon = 10\%$ above $z > 75$ km