Mechanisms in regulating the quasi-biennial oscillation in CESM and E3SM

2025 CESM CVCWG / ESPWG Working Group meeting

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Feb 5, 2025

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

1. Introduction how the deep convection scheme drives the gravity wave scheme which is responsible for the QBO

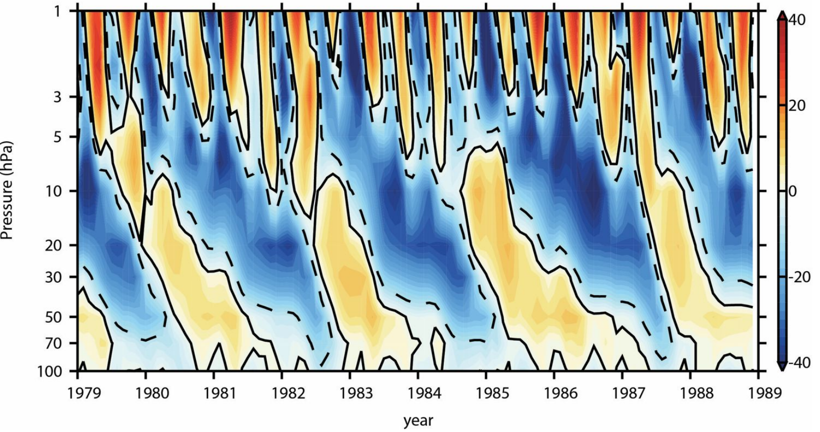
2. An important fix in the gravity wave scheme that is now integrated into CESM (**Yuanpu Li and Jack Chen**)

3. QBO is sensitive to the change of the tropical convection variance（take E3SMv2 as an example）(**Yuanpu Li, Jack Chen, Yaga Richter, Julio Bacmeister, James J. Benedict**)

4. A hypothesis that the Kelvin and mixed Rossby-gravity waves in the stratosphere can be partially intensified by the dissipation of parametrized gravity waves (**Yuanpu Li, Jack Chen, Kai Huang**)

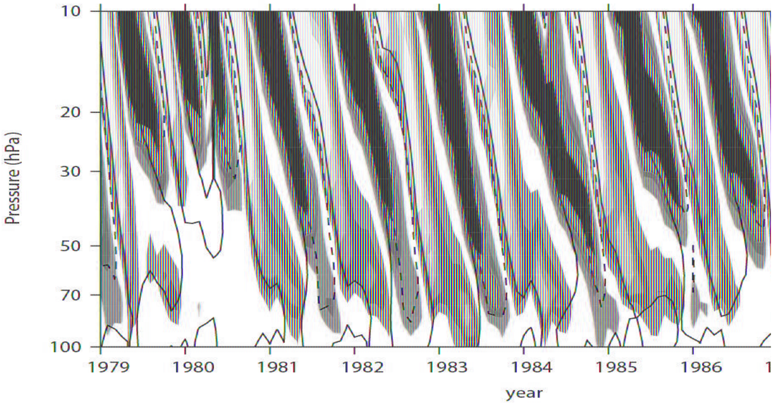
Quasi-Biennial Oscillation (QBO)

Equatorial zonal wind (ERA5)

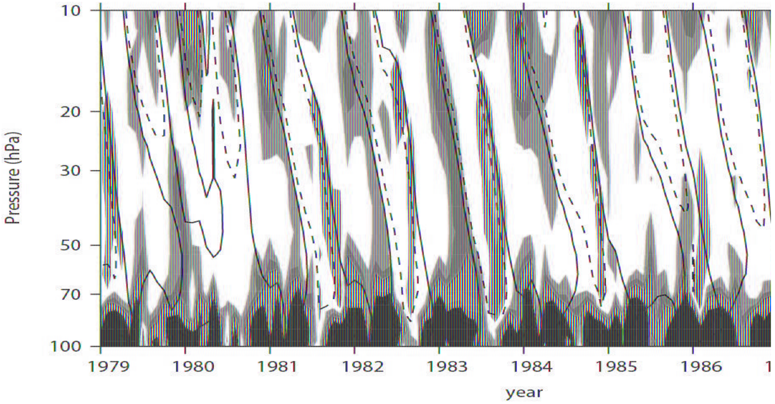


Forcings of QBO

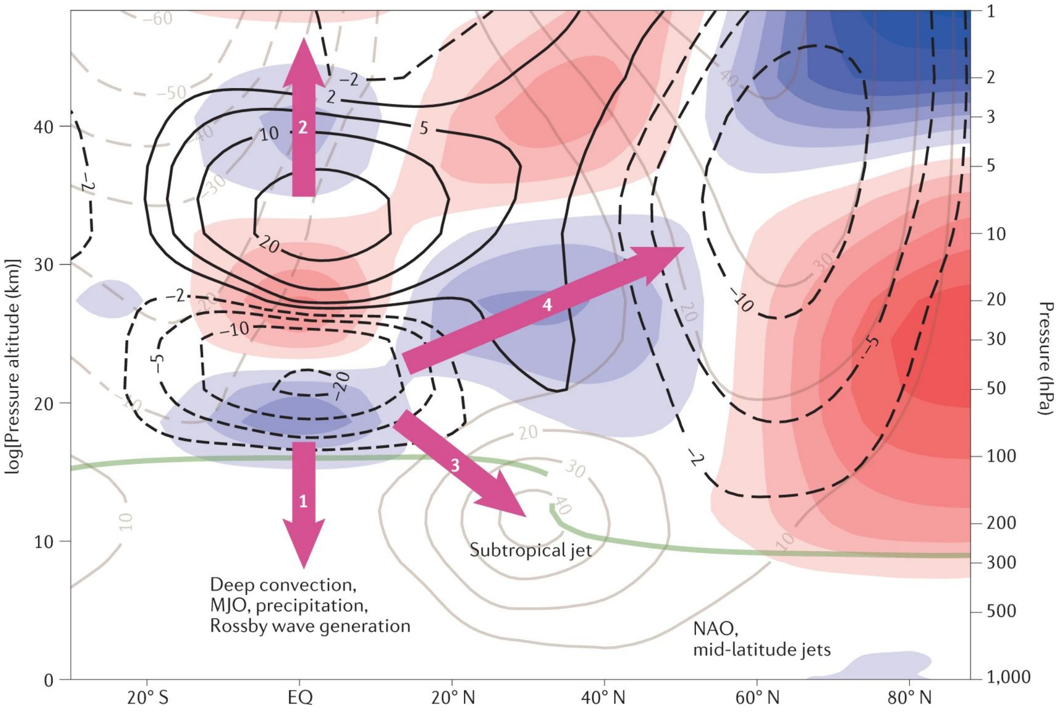
Gravity wave drag



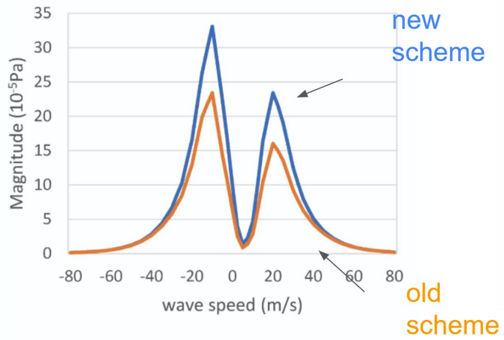
Large-scale wave drag (Kelvin, MRG et



The influence of QBO on other atmospheric modes



[*Anstey et al.*, 2022]



Frequency of convection

Convection scheme

D (depth of convection)

U (mean horizontal wind in convection)

Width and shape of GW spectrum

QBO

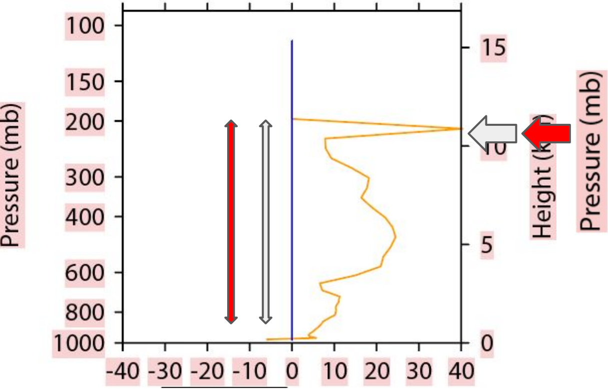
Qmax (the intensity of convection)

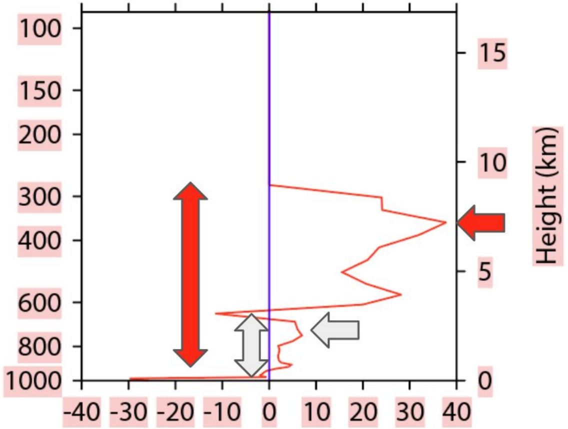
Amplitude of GW spectrum

Note: Scaled up by the <u>square of</u> Q_{max}

2. GW fix: The impact of the negative level midst of the convective heating profile on the QBO

Heating profile in a single convective time step in CAM



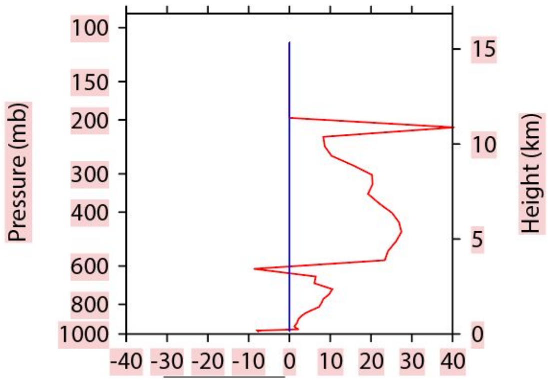


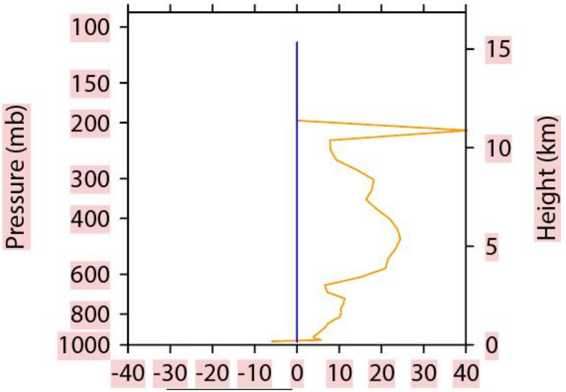
Grey arrow shows how old scheme treats the profile
Red arrow shows how new scheme treats the profile

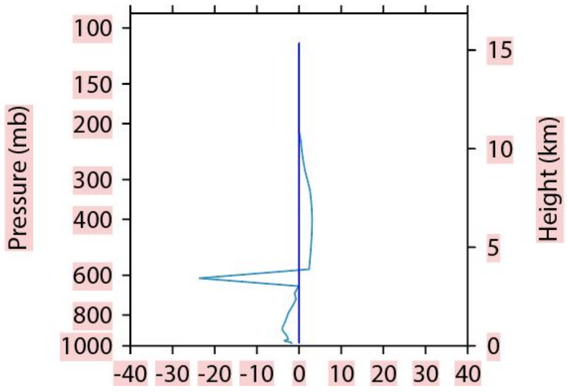
This kind of situation accounts for 13.5% in the total convective time

Heating profile in a single convective time step

Net heating = Latent heating + evaporation heating

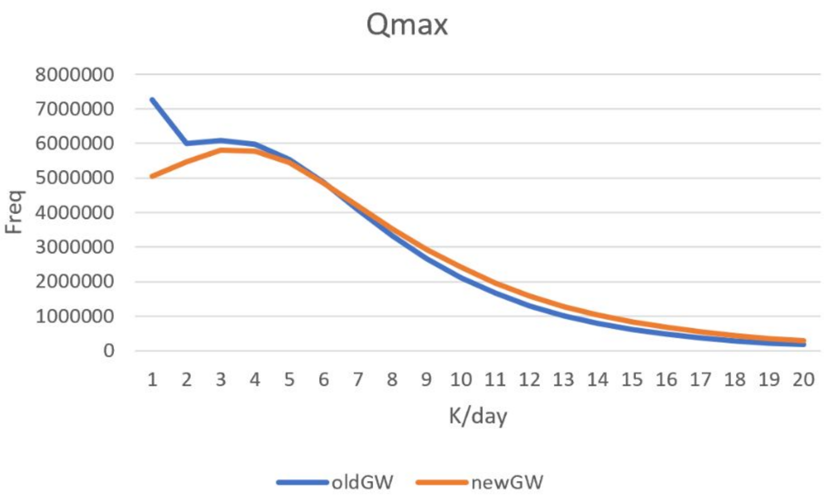


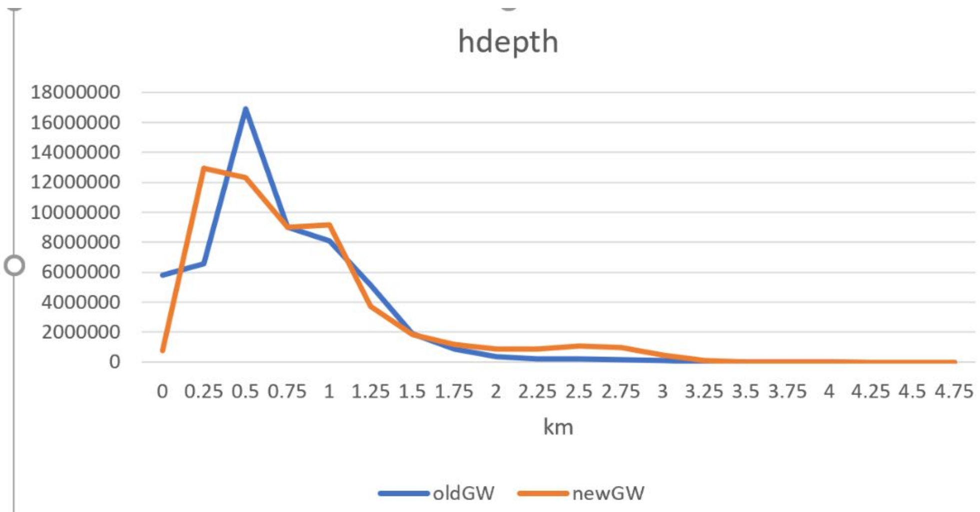




The negative heating at 600 hPa is from evaporation process.

PDF frequency distribution in two different GW scheme in CAM

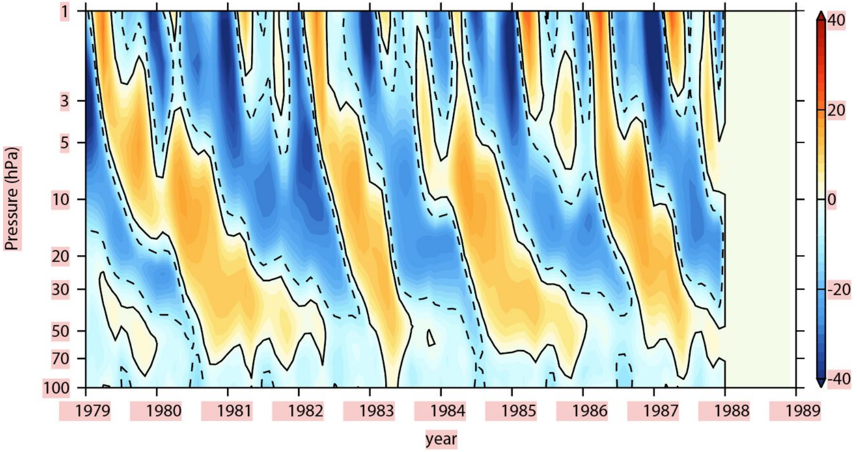




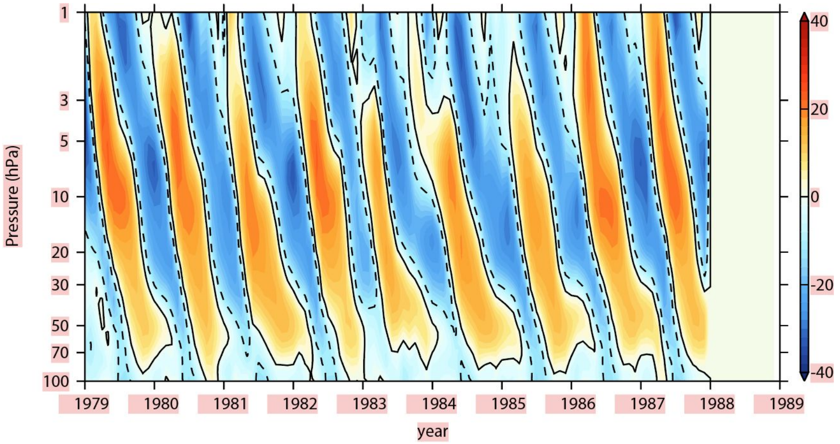
Impacts on GW momentum amplitude

Impacts on GW momentum spectrum shape

Old GW scheme

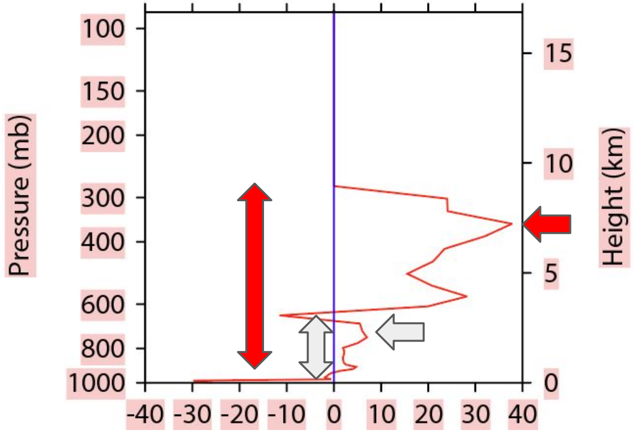


New GW scheme



Cam6_3_139 1degree

Heating profile in a single convective time step in EAM



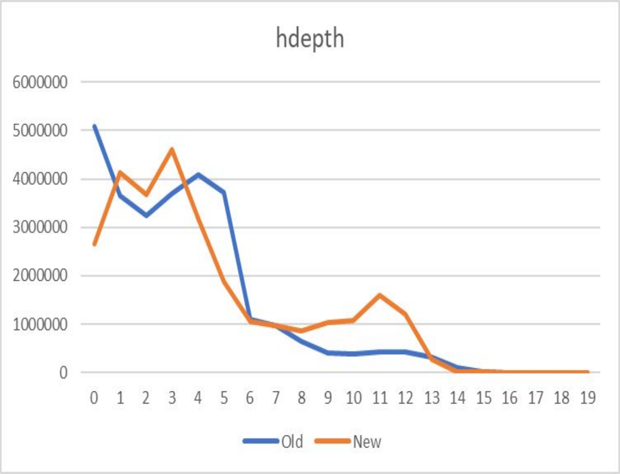
Heating rate

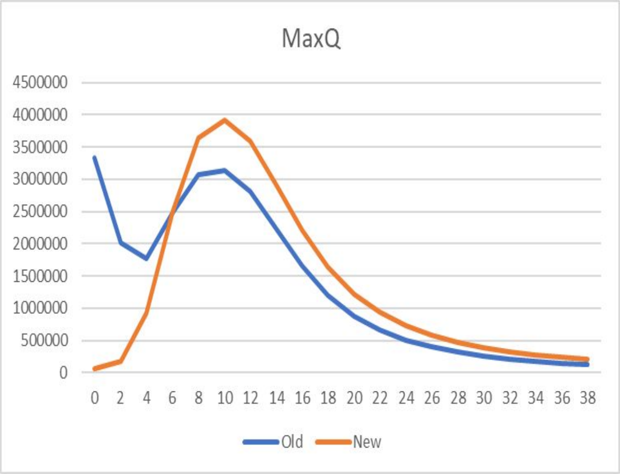
This kind of situation accounts for 27% in the total convective time

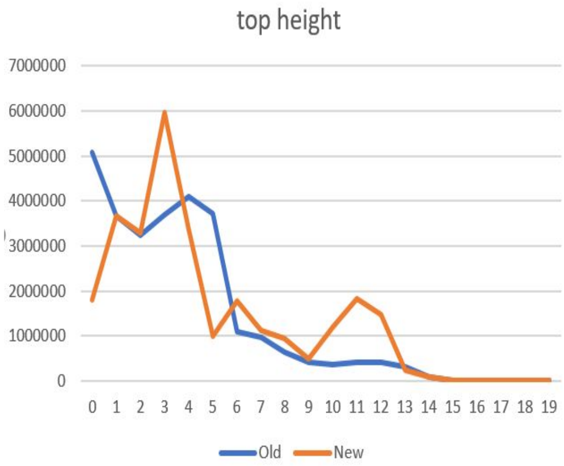
Grey arrows shows how current scheme treats the profile

Red arrows shows how new scheme treats the profile

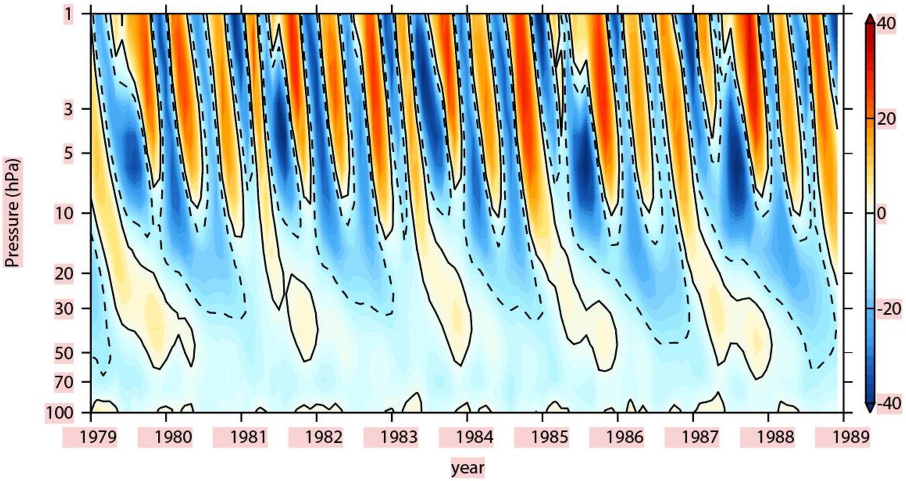
PDF frequency distribution in two different GW scheme in CAM



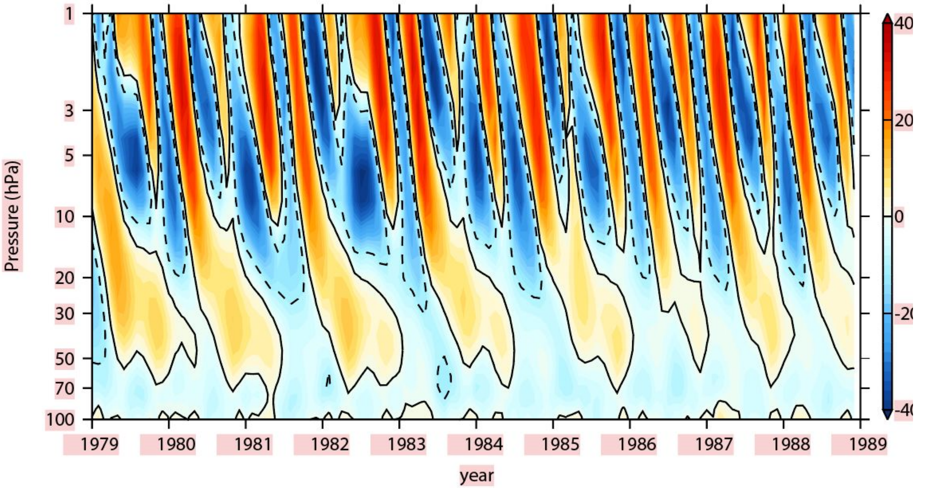




E3SMv2 old GW scheme



E3SMv2 new GW scheme

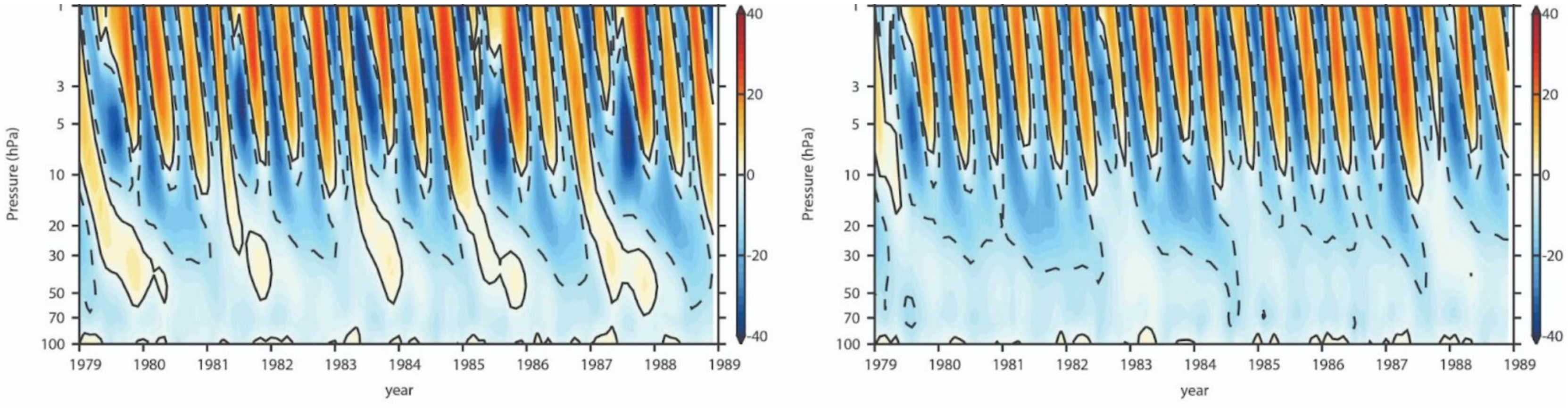


Conclusions:

1. New GW fix overcomes the underestimated Qmax issue
2. New GW fix intensifies the QBO amplitude and shortens its period
3. Based this fix, now the newest CAM is able to achieve a more realistic QBO by tuning (Mijeong Park talk tomorrow)

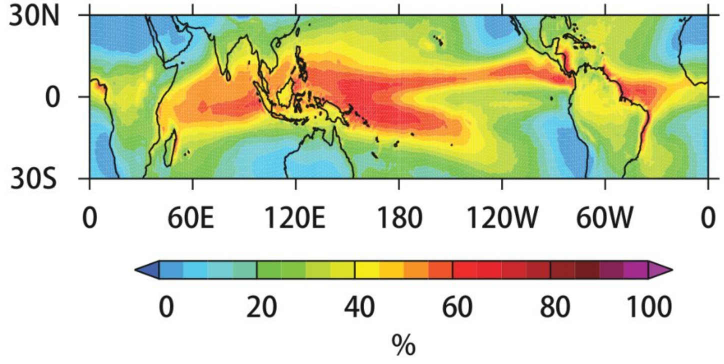
3. QBO is sensitive to the change in the tropical convection variance（take E3SMv2 as an example）

New deep convection parameterization   Old deep convection parameterization

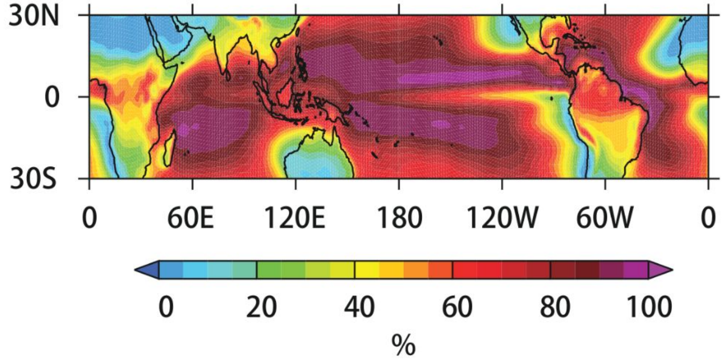


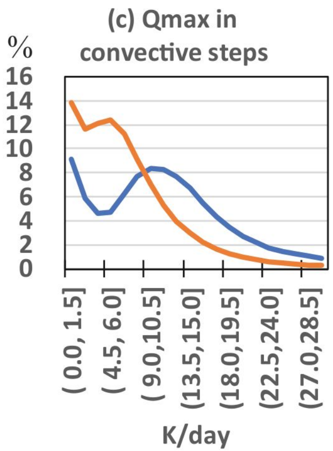
The update in deep convection scheme make **the convection less frequent**

New deep convection parameterization



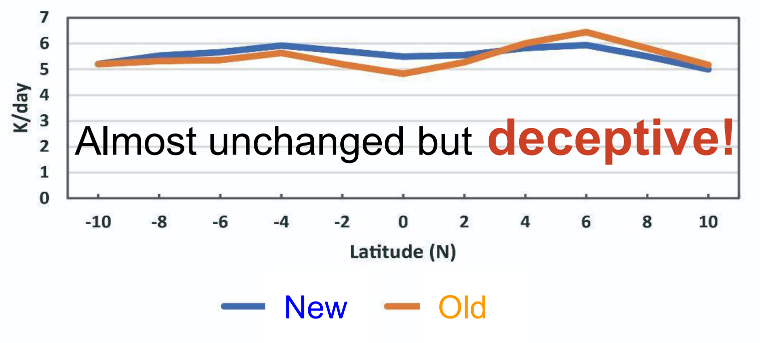
Old deep convection parameterization



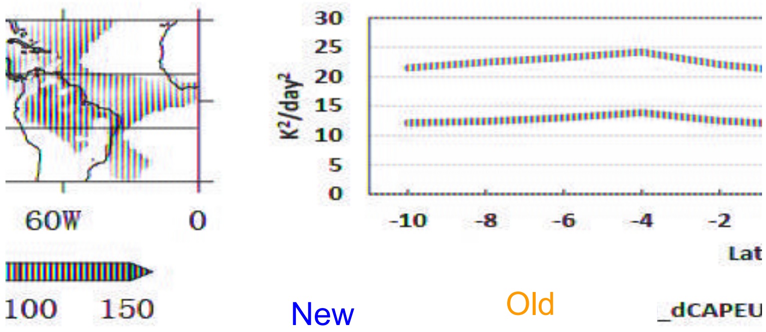


The update in deep convection scheme make **the convection more intense**

Zonal and time mean of Qmax



Zonal and time mean of Qmax square

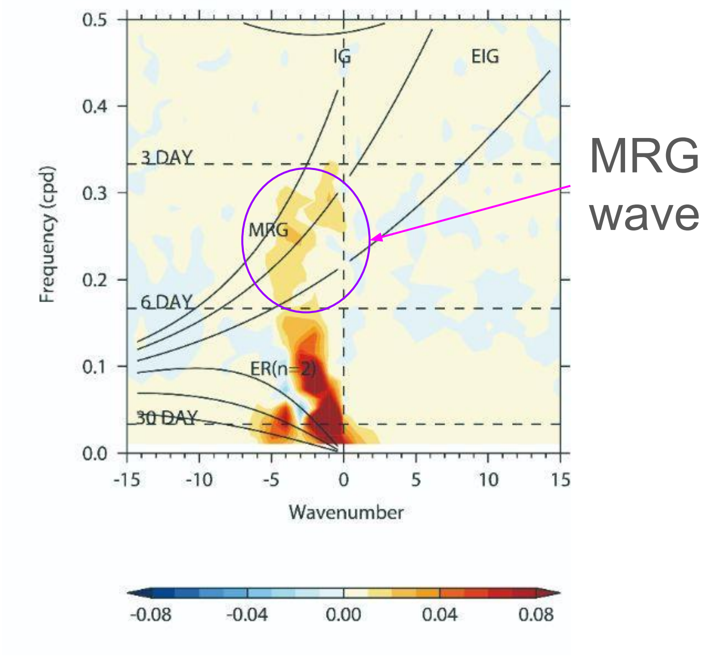


Conclusion: The QBO simulated by E3SMv2 is found to be most sensitive to the vertical maximum of convective latent heating calculated by the deep convection scheme

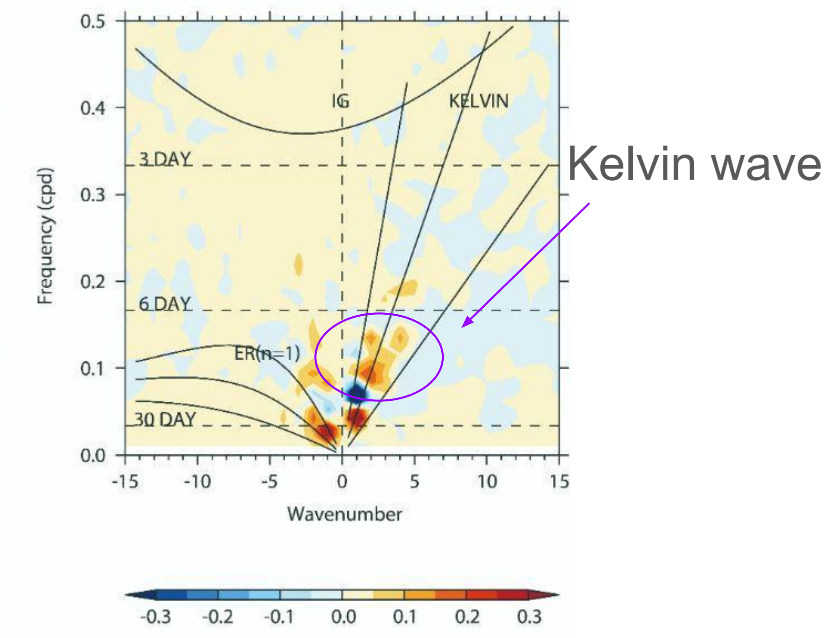
4. A hypothesis that the Kelvin and mixed Rossby-gravity waves in the stratosphere can be partially intensified by the dissipation of parametrized gravity waves

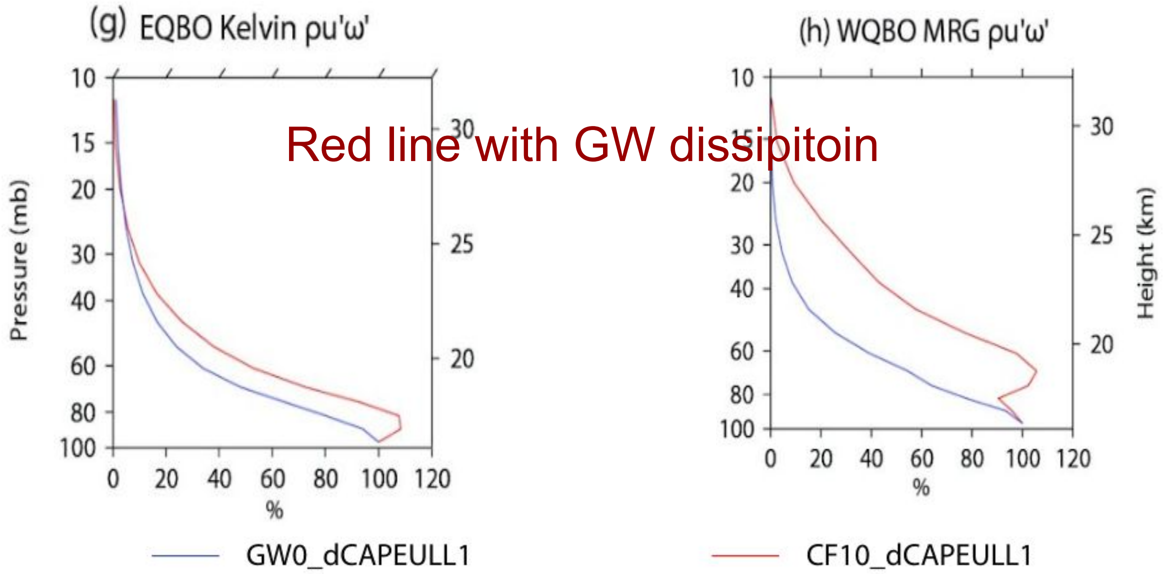
Difference in space-time spectra of zonal wind (U) at 45 hPa (with gravity waves-without gravity wave)

Antisymmetric wave



Symmetric wave





The composited (g) Kelvin wave profiles in the easterly QBO and (h) MRG wave profiles in the westerly QBO segments for CF10_dCAPEULL1 and GW0_dCAPEULL1. The momentum fluxes at different levels in (g), (h) are normalized by those at 96 hPa to illustrate the relative enhancement or decrease of the stratospheric fluxes to those from the tropopause.

There is evidence that planetary wave intensification is present in the stratosphere due to dissipation of parameterized gravity waves. (This mechanism is not fully understood and needs more theoretical works)

Conclusions:

1. An important GW fix in the gravity scheme that is now integrated to the newest CAM and WACCM (preparing a paper)

2. QBO is sensitive to the change of the tropical convection variance

1. A hypothesis that the Kelvin and mixed Rossby-gravity waves in the stratosphere can be partially intensified by the dissipation of parametrized gravity waves

Li, Y., Chen, C.-C., Benedict, J. J., Huang, K., Richter, J. H., & Bacmeister, J. (2025). Mechanisms in regulating the quasi-biennial oscillation in E3SM version 2. Journal of Geophysical Research: Atmospheres, 130, e2024JD041868. https://doi.org/10.1029/2024JD041868

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