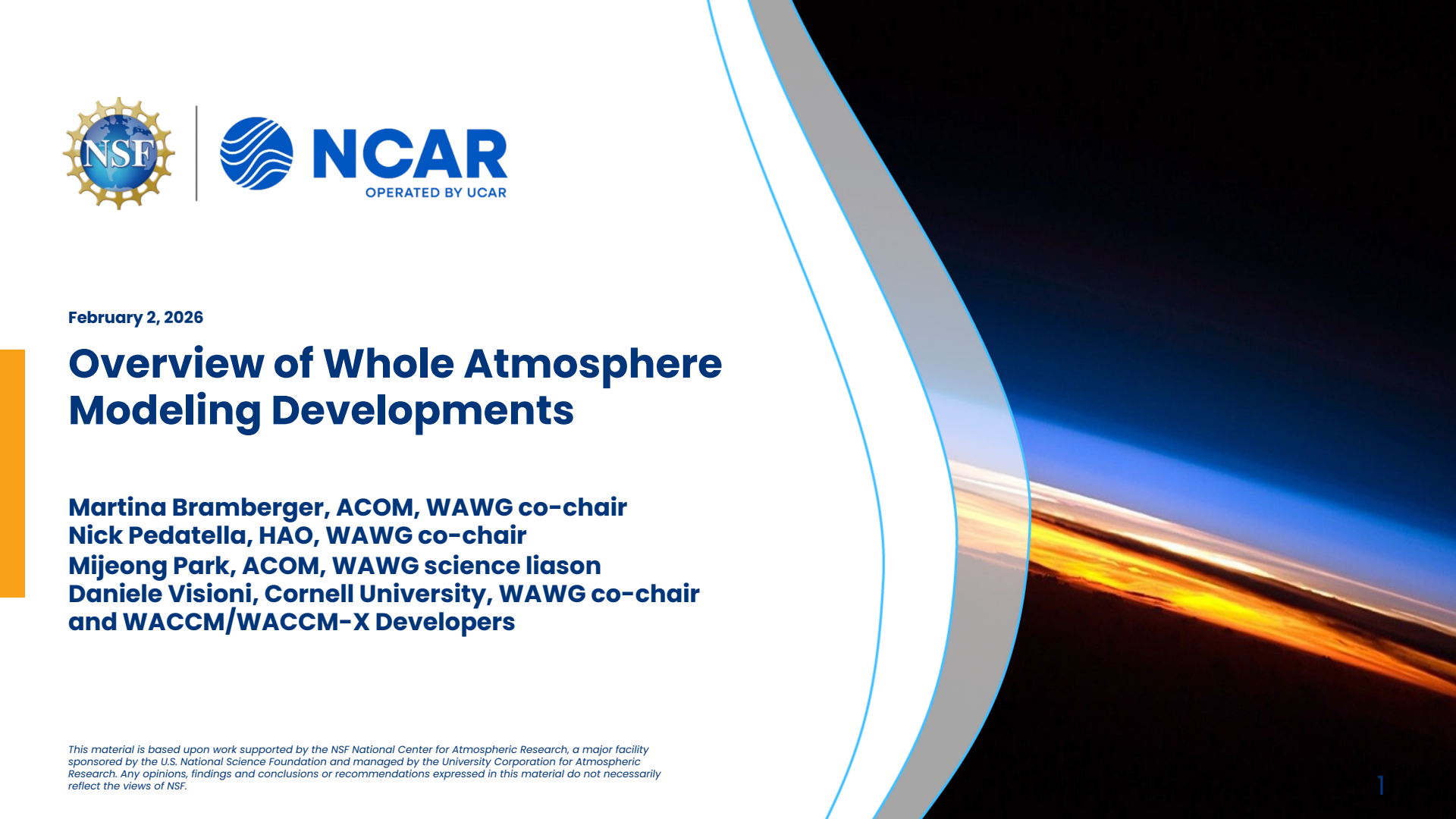

February 2, 2026

Overview of Whole Atmosphere Modeling Developments

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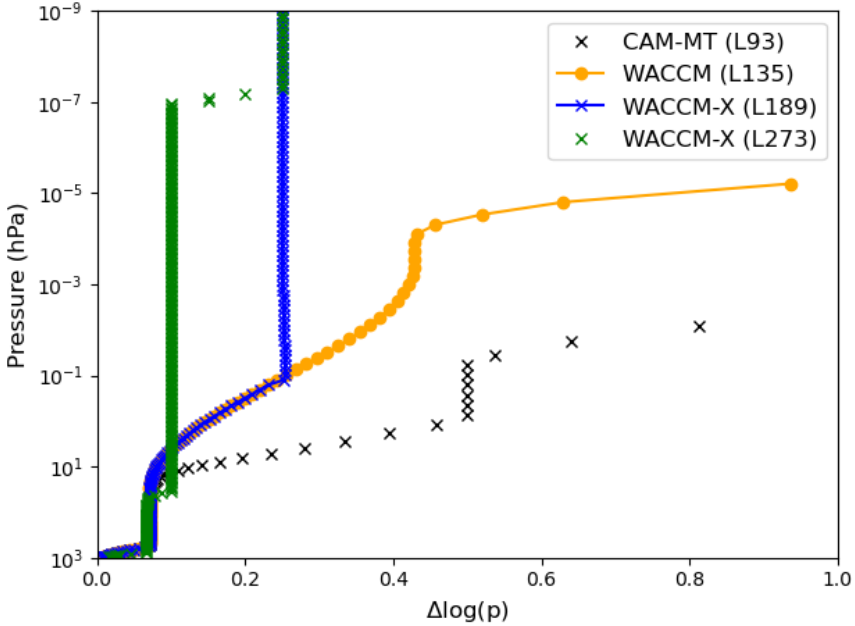
Whole Atmosphere Objectives for CESM3

Priority development objectives:

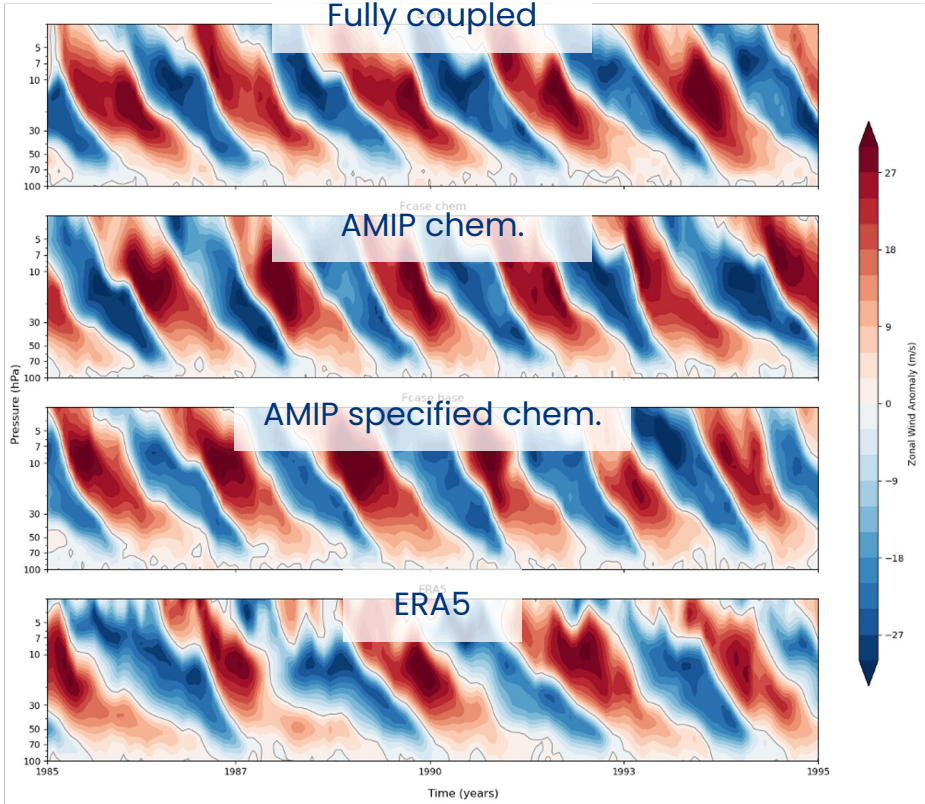
- Good QBO for both CAM-MT and WACCM
- Seasonal cycle of winds/temperatures in the stratosphere-mesosphere and the impact on chemistry (CAM-MT, WACCM)
- Thermosphere extension of SE dycore, ionosphere-thermosphere climatology & variability (WACCM-X)



Outline

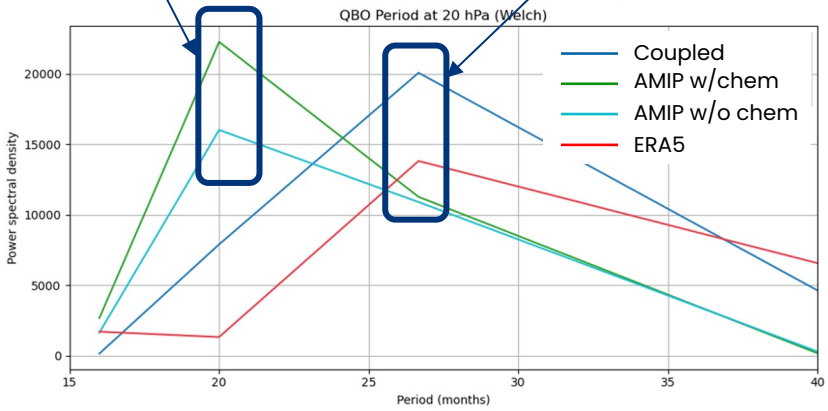
- Tuning of QBO and polar vortex: Impact of interactive chemistry and ocean coupling
- WACCM7 MLT diagnostics
- Frontal gravity wave bug
- WACCM-X developments

Impact of chemistry and ocean coupling on QBO



Adding chemistry has no impact on period

Adding ocean slows down period



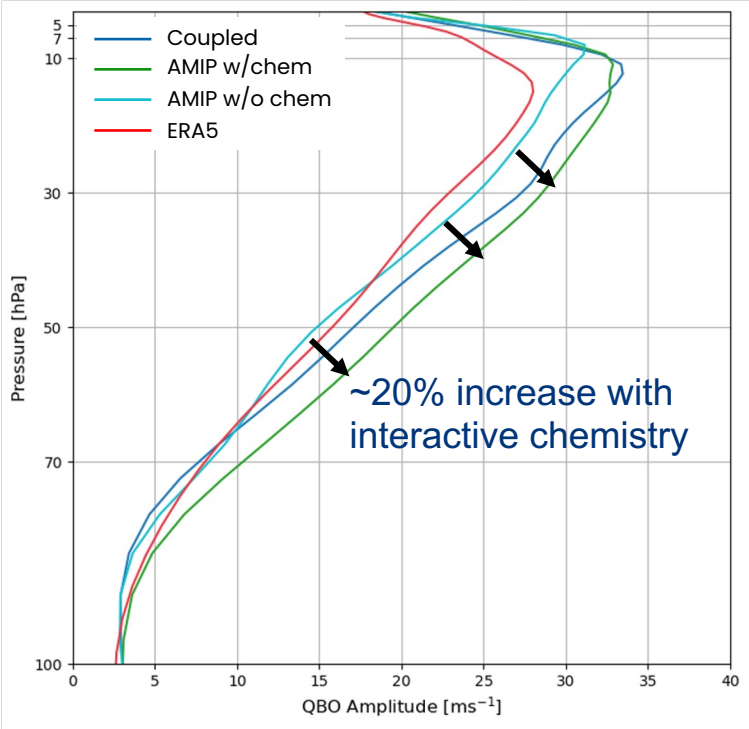
AMIP specified chemistry/oxidants
AMIP with interactive chemistry
Fully coupled, interactive chem.

Figures: Martina Bramberger

Results for CAM-MT

Impact of chemistry and ocean coupling on QBO

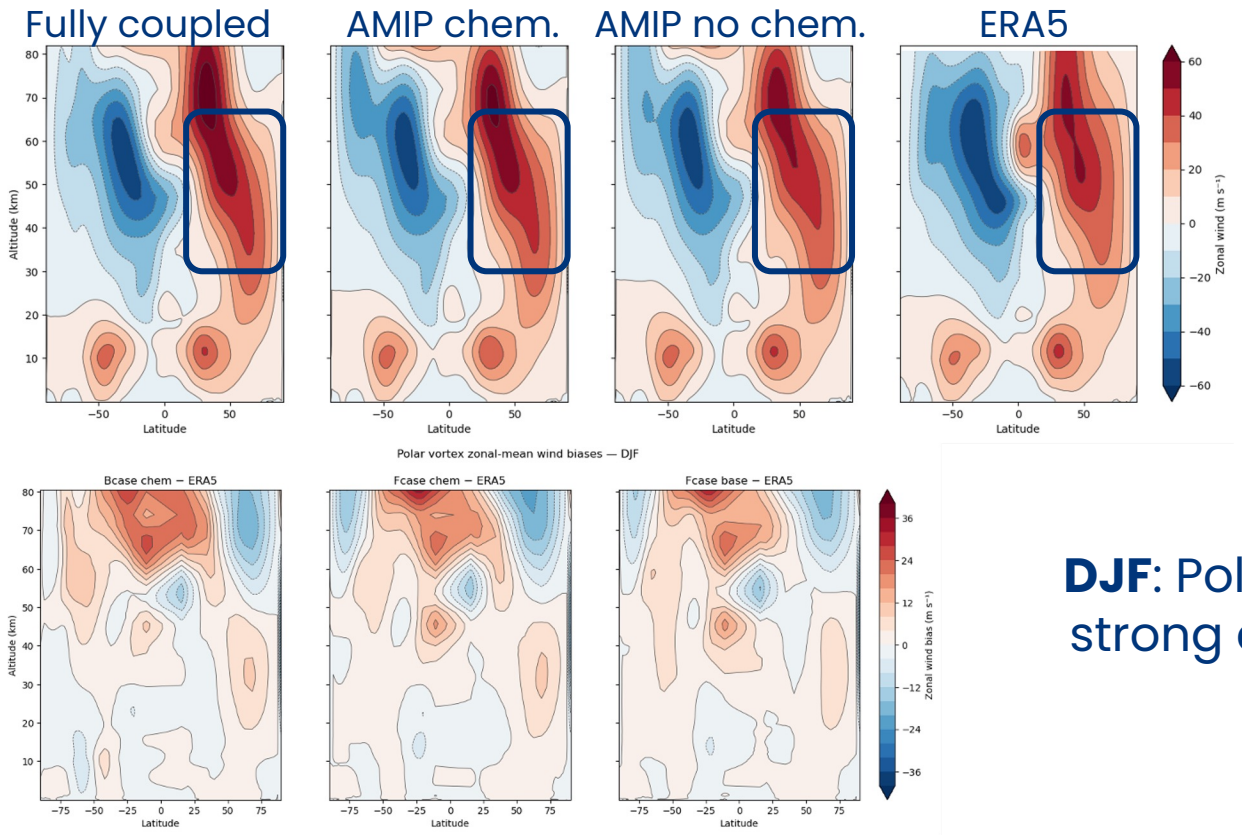
- Interactive chemistry is important for achieving adequate QBO amplitudes
- Adding ocean slows down the period, with more minor impacts on the amplitude
- Achieving good QBO amplitude and period is **only possible with interactive chemistry**
- Runs with specified chemistry will not fully reproduce the QBO



Figures: Martina Bramberger

Results for CAM-MT

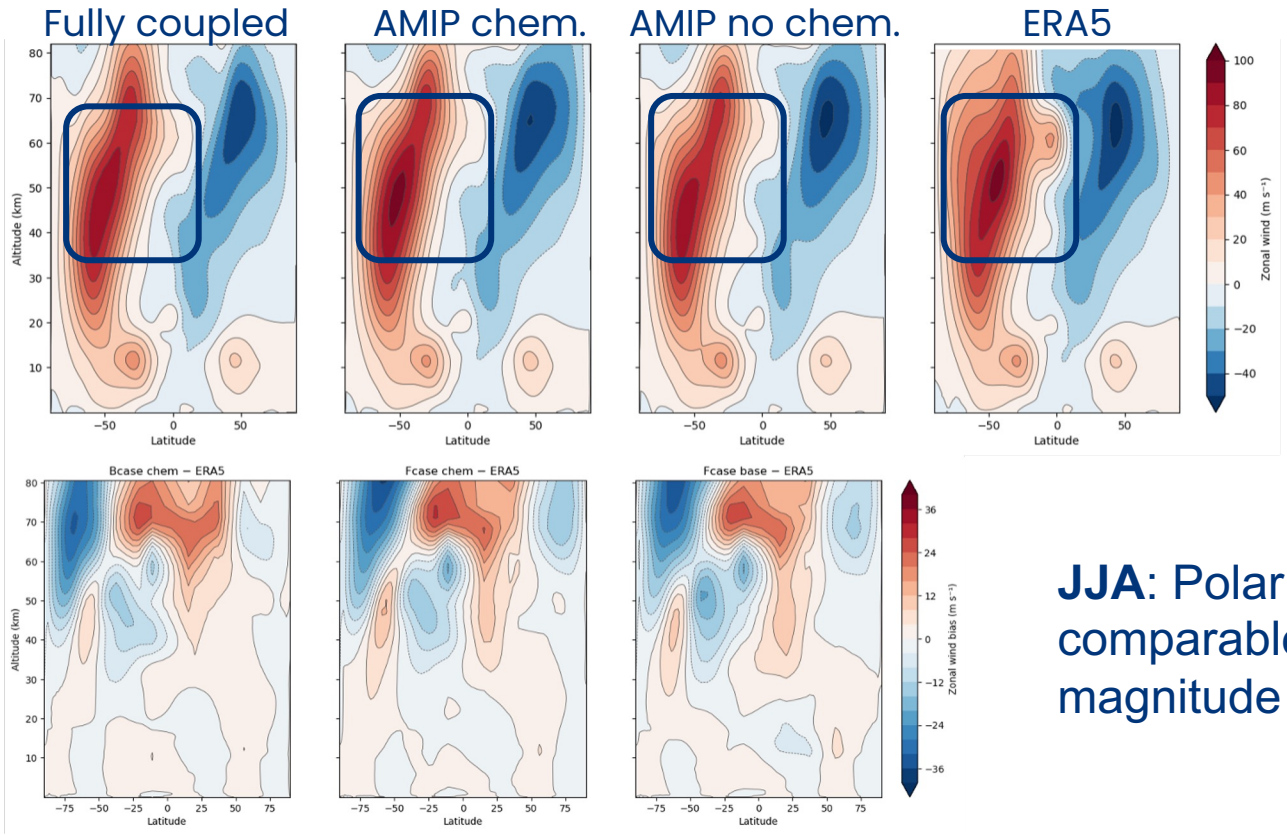
Impacts of chemistry and ocean coupling on polar vortex



DJF: Polar Vortex in NH too strong compared to ERA5

Figures: Martina Bramberger

Impacts of chemistry and ocean coupling on polar vortex

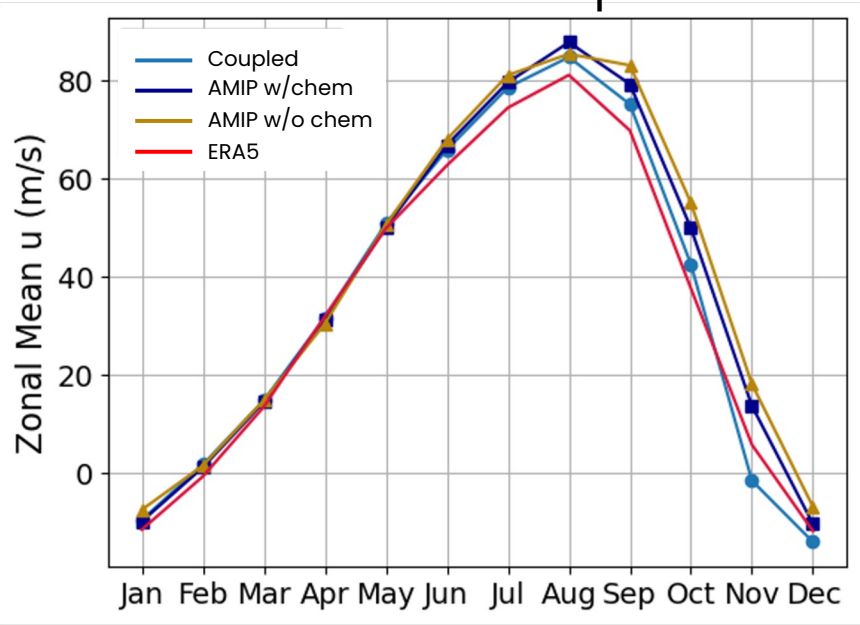


JJA: Polar vortex in SH comparable to ERA5 in magnitude and structure/shape

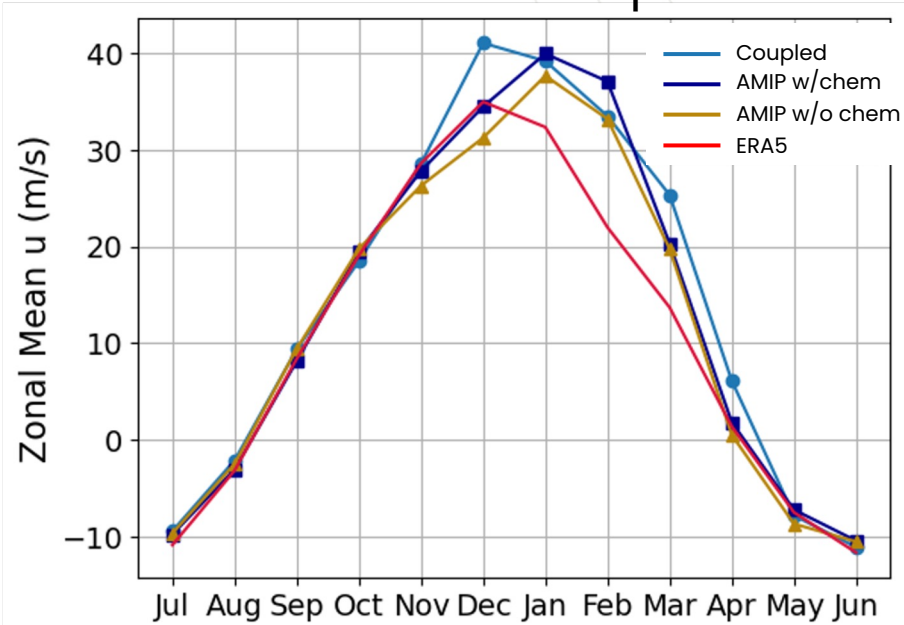
Figures: Martina Bramberger

Impacts of chemistry and ocean coupling on polar vortex

Southern Hemisphere



Northern Hemisphere



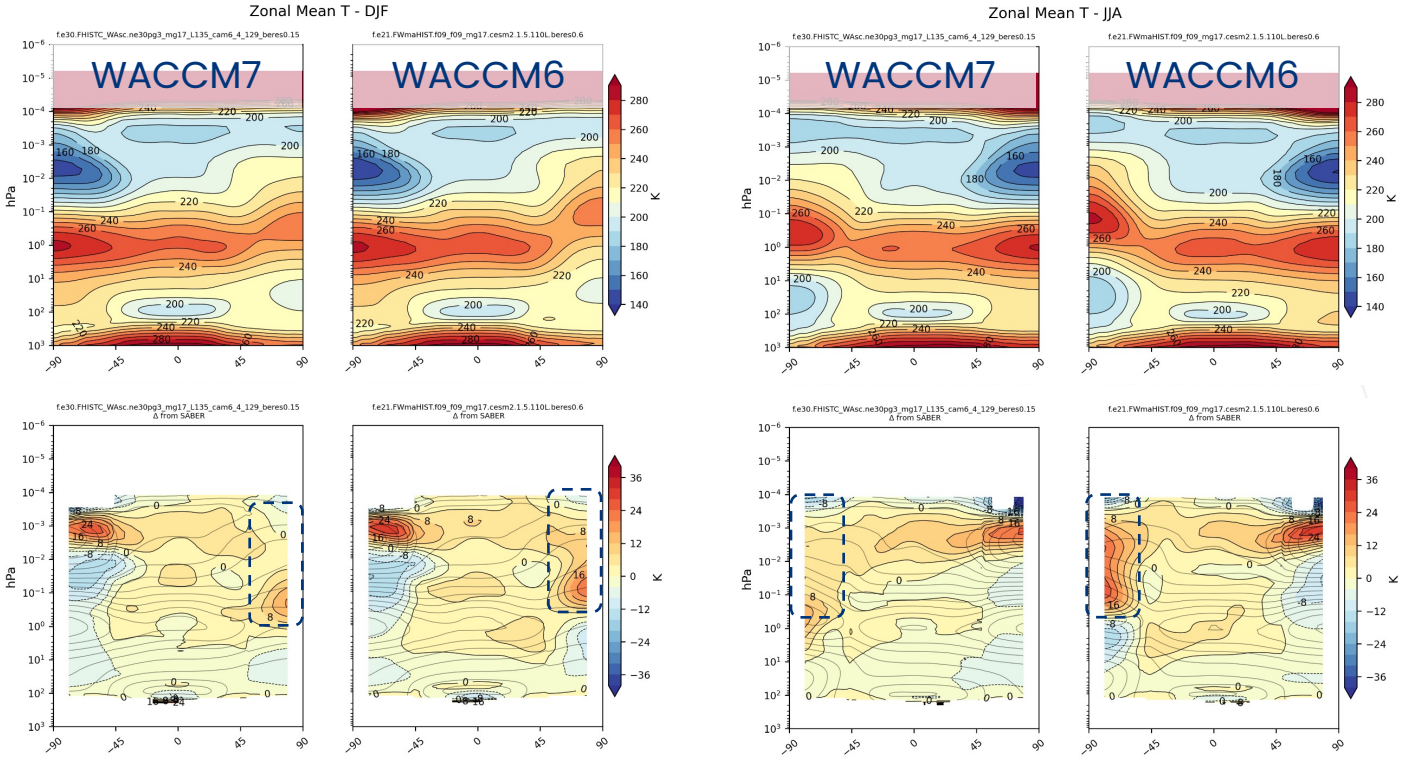
Polar vortex largely insensitive to interactive chemistry and ocean coupling

Final tuning will be done with AMIP simulations without chemistry

Figures: Martina Bramberger

Results for CAM-MT

WACCM7 MLT Diagnostics



MLT temperatures in WACCM7 largely improved relative to WACCM6 despite minimal tuning

Some tuning needed to address wind biases, especially in the winter hemisphere

Frontogenesis function bug fix

Bug – Horizontal gradients of T, U, and V calculated on hybrid model coordinates instead of pressure levels.

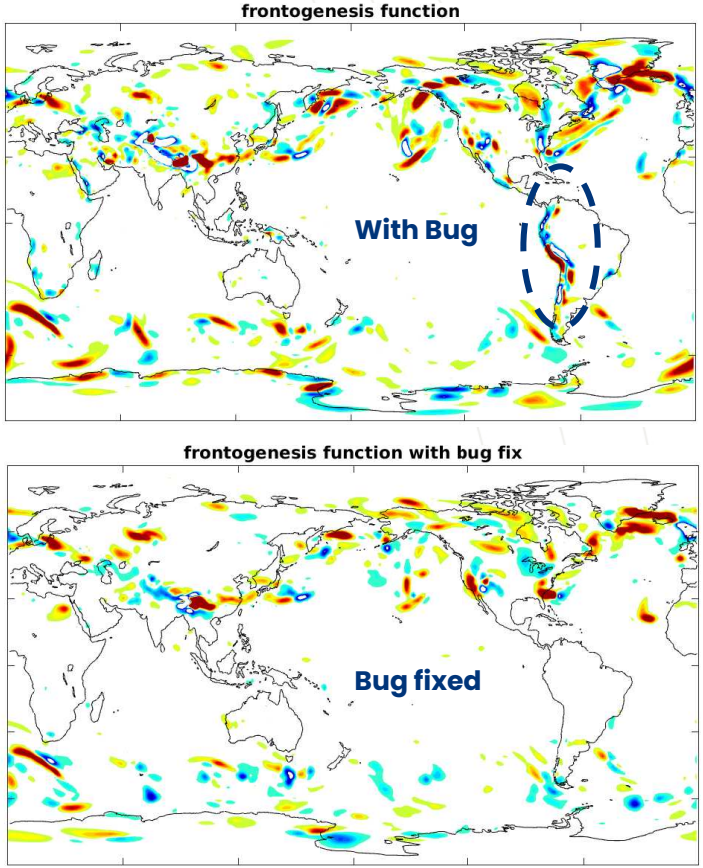
Issue - Leads to artifacts in the vertical gradients of horizontal gradients of T, U, V in the frontogenesis function calculation especially for ~1 deg model configurations.

Fix – Correction terms are added e.g., dt/dx (at pressure level) = dT/dx (at hybrid level) **- dT/dp * dp(at hybrid level)/dx**

From Kai Huang, see also Chen et al. (2021)

Fix implemented in CESM3 (CAM-MT, WACCM6, WACCM7)

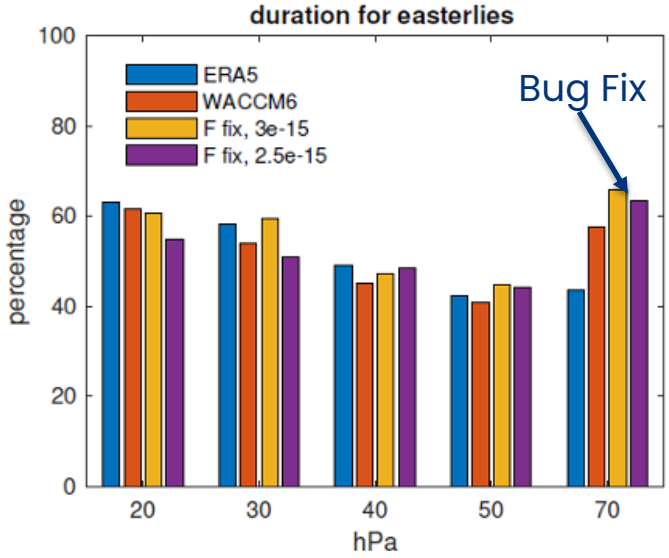
CESM2 WACCM6: TBD



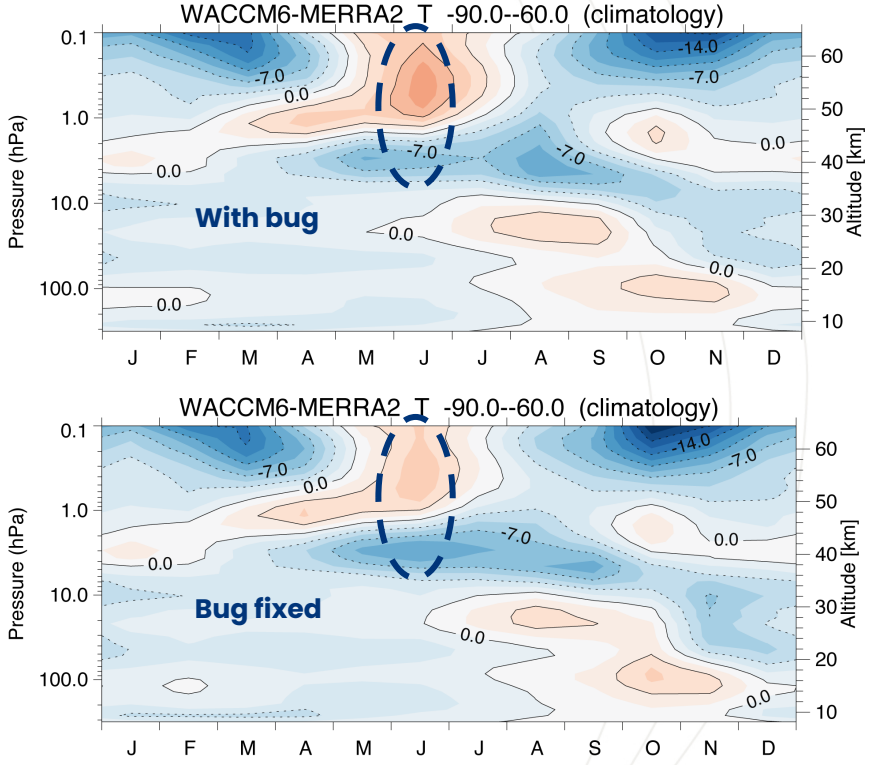
 | Figures: Jack Chen

Impacts of frontogenesis function bug fix

QBO easterlies become stronger and more prevalent



Reduces SH polar cap (60-90S) temperature bias above ~1 hPa



Figures: Jack Chen & Mijeong Park

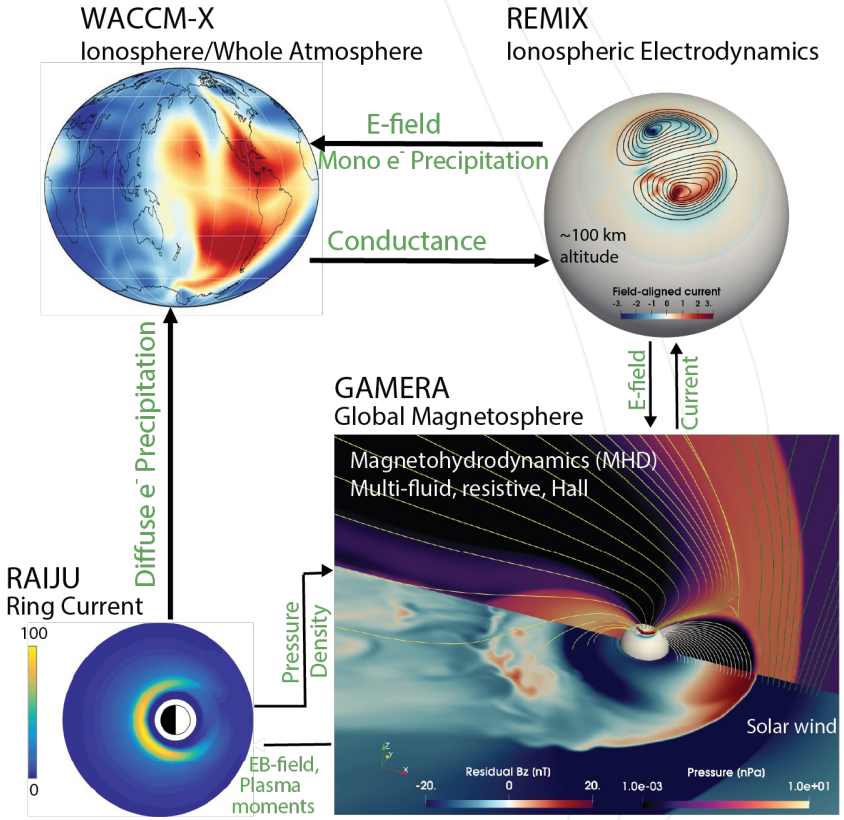
Recent WACCM-X Developments

For CESM3:

- Thermosphere extension of SE dycore
- High resolution capability, including specified meteorology
- Updated thermosphere chemistry

Developments in-progress (for CESM3.x?):

- 3D dynamo / global ionospheric dynamo
- Implementation of E-region ion transport (developed at University of Leeds)
- Pressure upper boundary for stand-alone MPAS (HAO & MMM)
- Two-way coupling between WACCM-X and GAMERA magnetosphere model (in partnership with JHU-APL)



Summary and Conclusions

- Have made significant progress in tuning the QBO and polar vortex for CAM-MT and WACCM
- Interactive chemistry is needed to achieve an adequate QBO
- Will soon begin to tune the MLT dynamics now that the stratosphere tuning is largely set
- Use cases for CAM-MT vs. WACCM needs to be evaluated to provide community guidance
- Continue to advance WACCM-X capabilities, improving space weather modeling within CESM