Meteorologically constrained high-resolution WACCM-X simulations

CESM Joint AMWG, CCWG, ESPWG, CVCWG, and WAWG Winter WG Meeting

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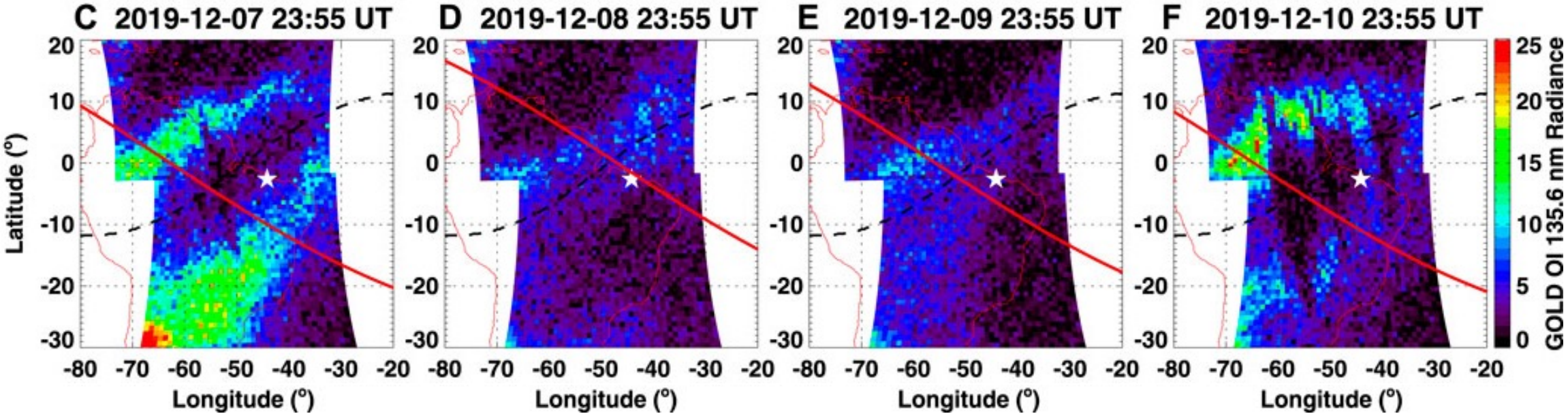
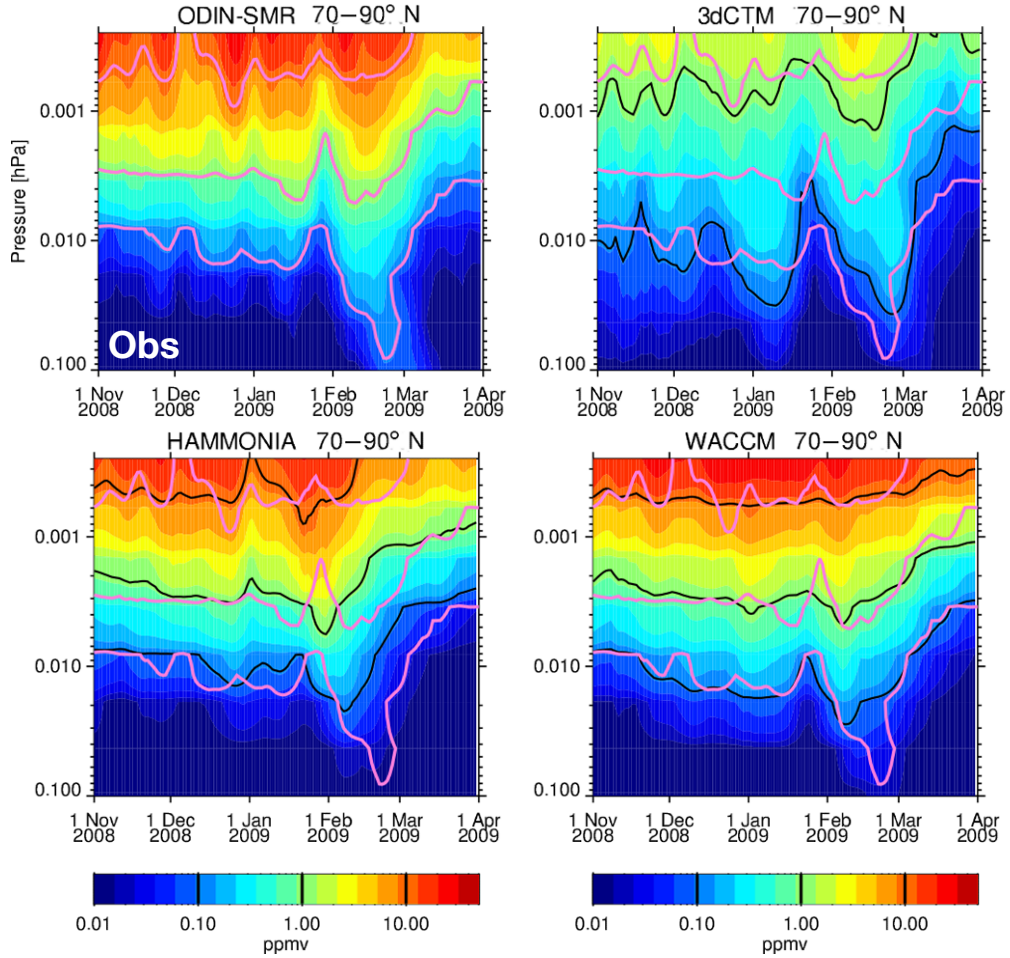
Motivation: Simulate the day-to-day variability of the middle-upper atmosphere, including the variability and impacts of small-scale waves



- An example of the day-to-day variability of interest is shown in Aa et al. (2023).
- NASA GOLD observations show day-to-day variability in the strength of the equatorial anomalies and occurrence of equatorial plasma bubbles (EPBs).
- High-resolution simulations are needed to reproduce EPBs (e.g., Huba and Liu, 2020).

Motivation: Coarse resolution chemistry climate models tend to underestimate NO and the transport downward into the stratosphere following SSWs



High-resolution simulations improve NO in the MLT (Hanli Liu presentation on Wednesday)

Need specified dynamics simulation to simulate transport during SSWs

(Funke et al., 2017)

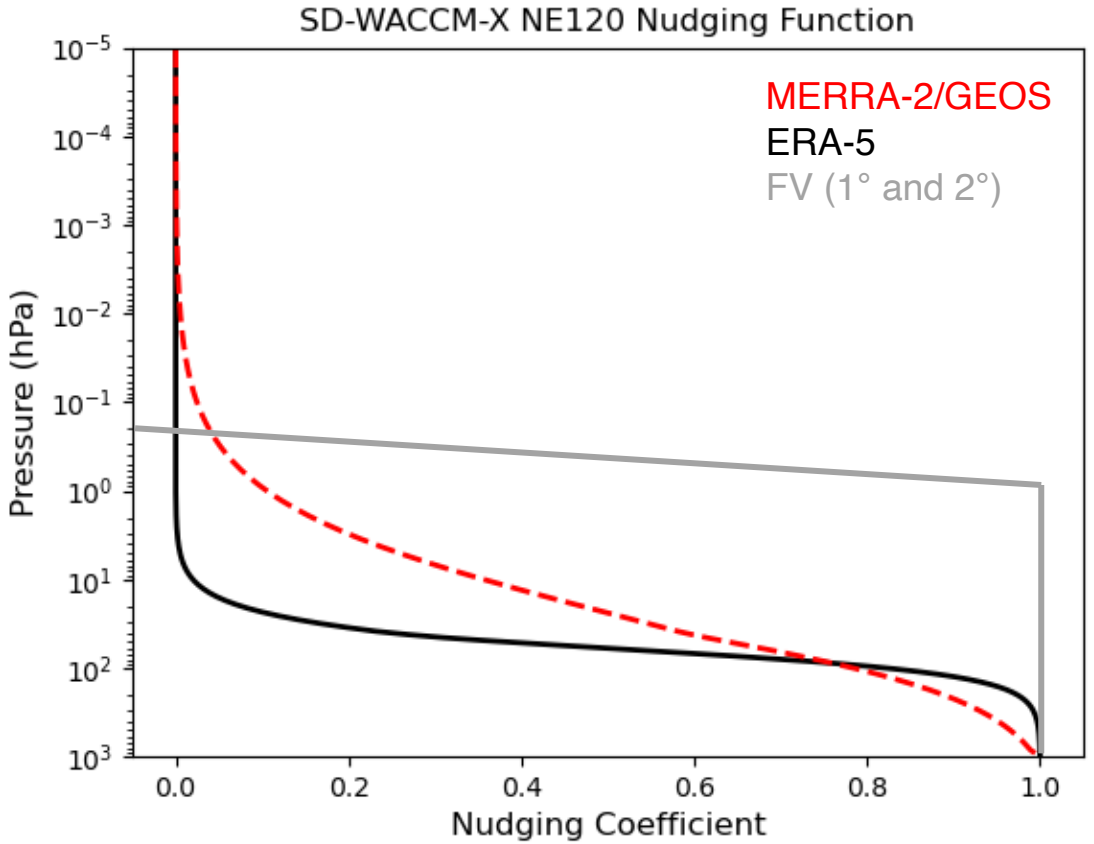
The high-resolution nudging is implemented in the model physics and uses a different vertical profile and strength compared to FV low-resolution implementation

$$X_{tend} = \alpha\tau(p)\frac{n}{86400}[X_{met} - X_{model}]$$

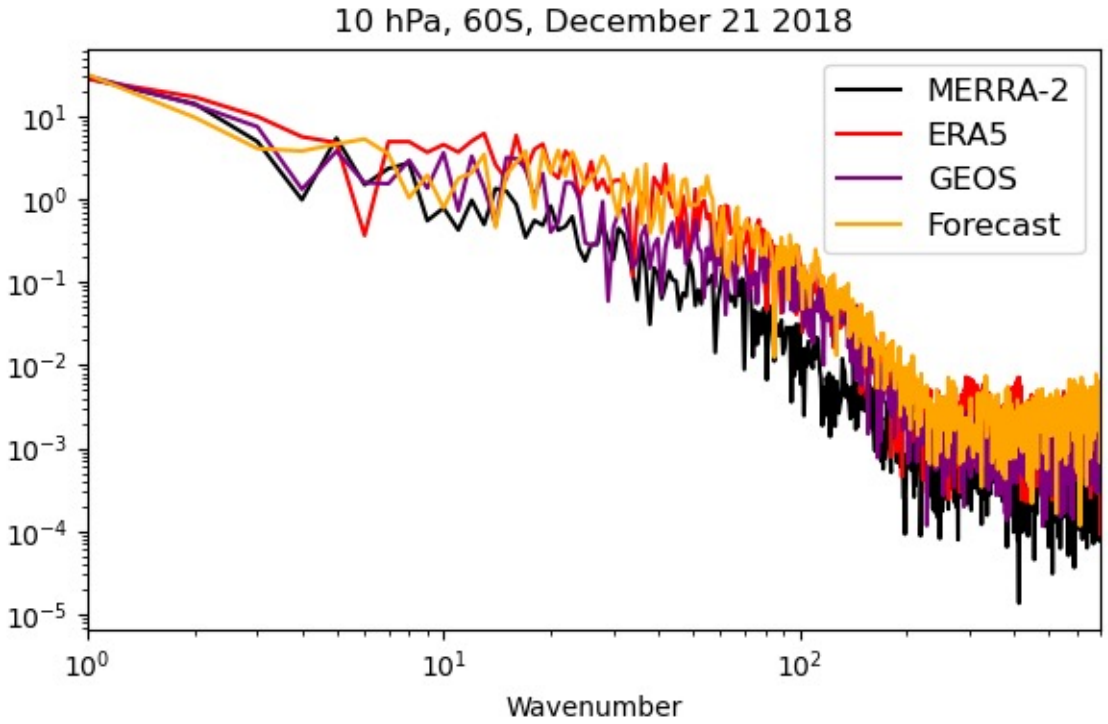
$$\alpha = 0.3$$

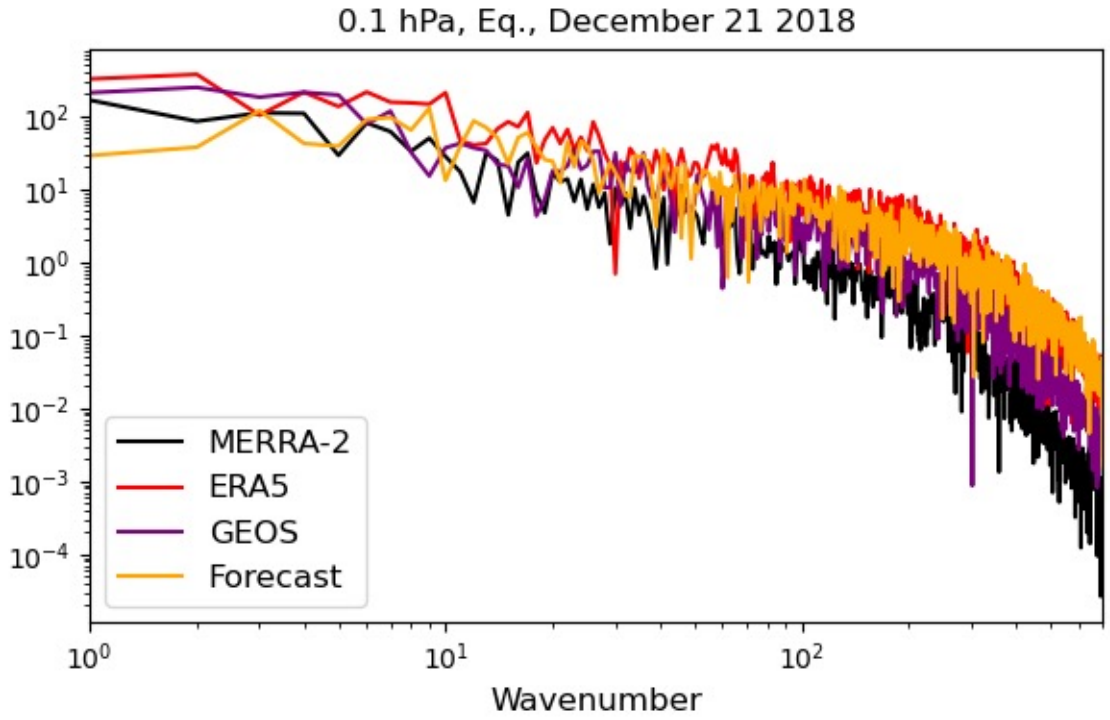
$$n = 8 \text{ (MERRA-2)}$$

$$n = 24 \text{ (ERA-5)}$$



Simulated wave spectrum is sensitive to the reanalysis used for the nudging



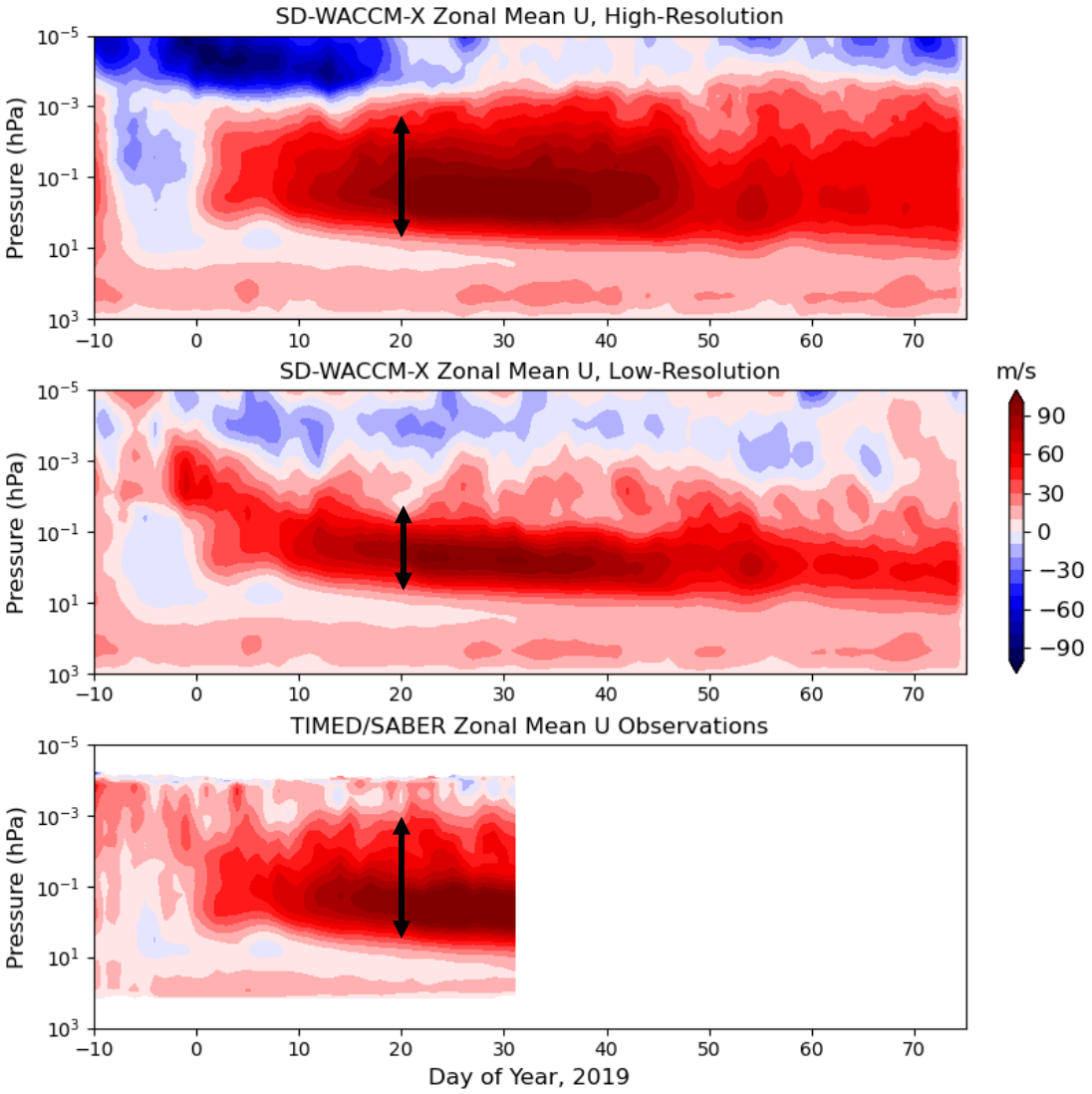


- Four day forecast used as a reference wave spectrum
- Nudging to MERRA-2 damps waves compared to GEOS and ERA-5
- Nudging to ERA-5 best matches the forecast wave spectrum

High-resolution nudged WACCM-X simulations

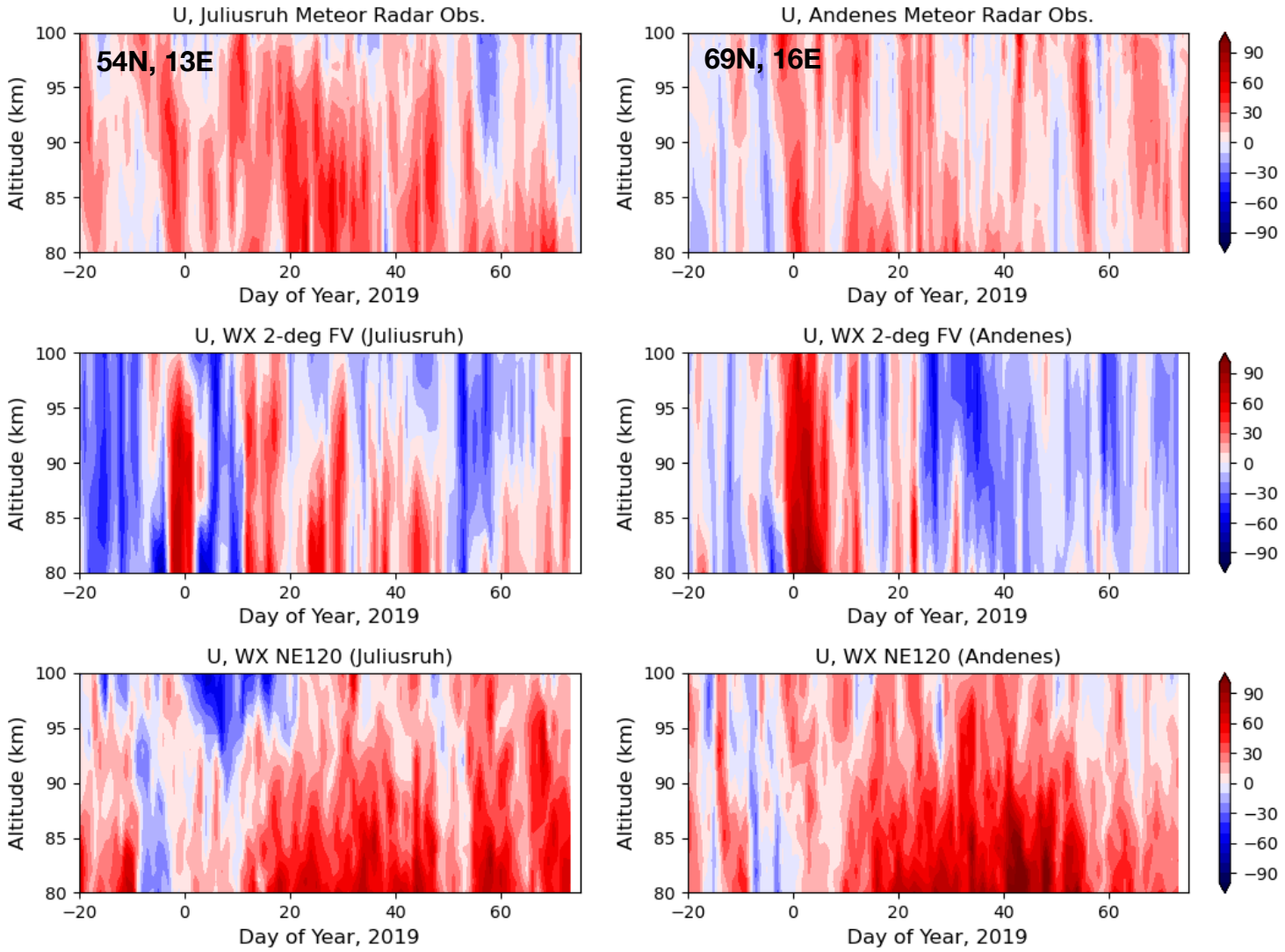
- 2018-2019 sudden stratospheric warming (MERRA-2, ERA5 in progress)
- 2023-2024 sudden stratospheric warming (GEOS)
- Hurricane Helene (GEOS)

Comparison of zonal mean zonal winds in WACCM-X to observations show both good and bad features in high-resolution simulations



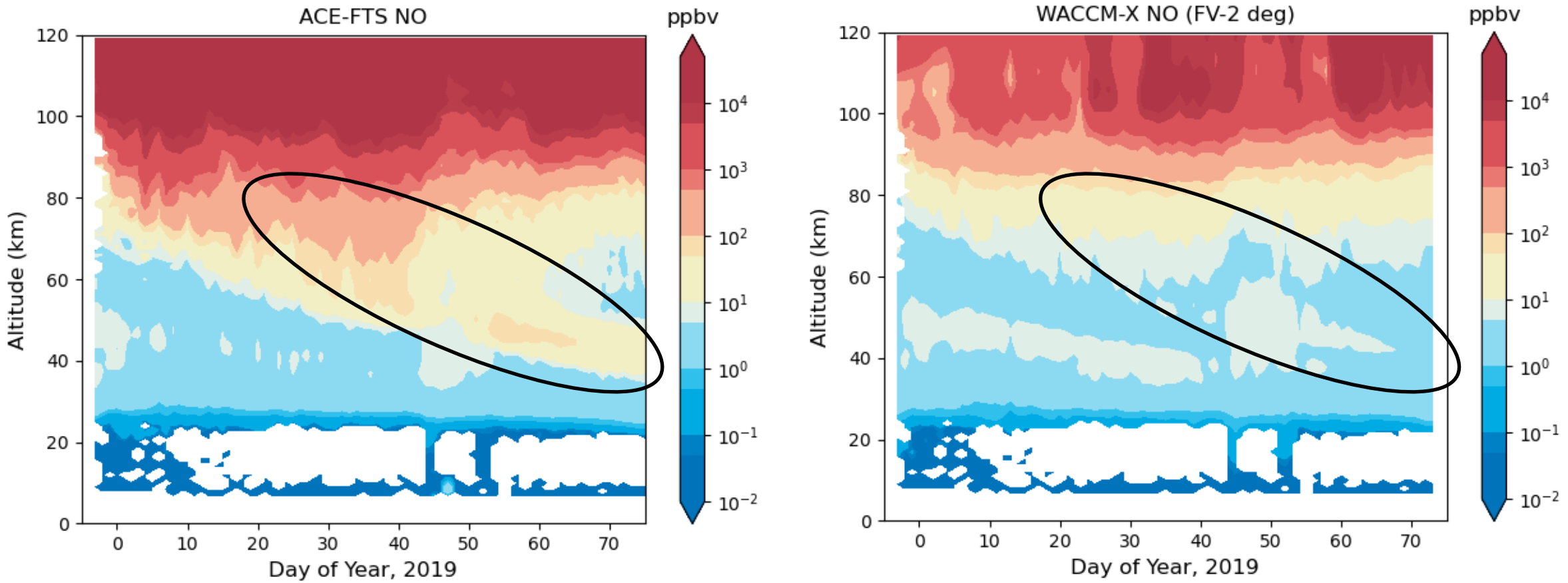
- High resolution simulation better captures the vertical extend of the eastward winds.
- Polar vortex too strong in high-resolution simulations in late January – February.
- Runs have no parameterized GWs (updated ERA-5 run with GW parameterization in progress)

Comparison of zonal mean zonal winds in WACCM-X to observations show both good and bad features in high-resolution simulations

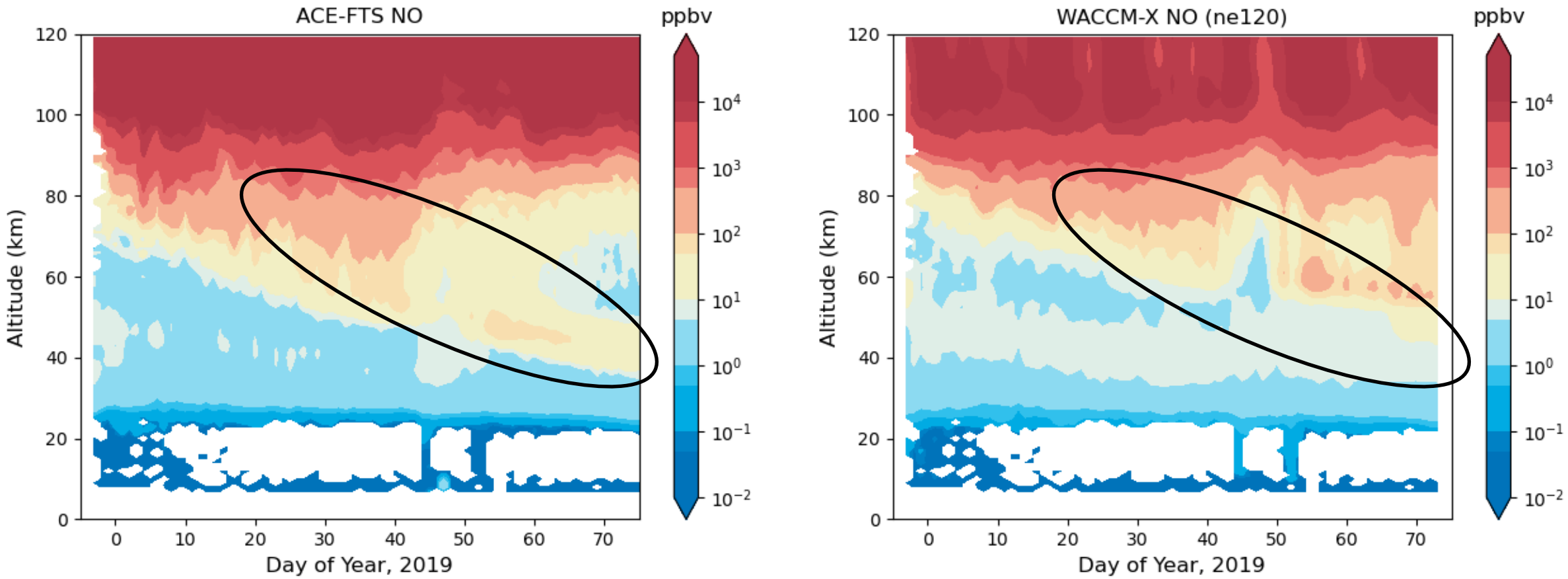


- High-resolution simulation better simulates the eastward winds in the MLT
- Aspects of the day-to-day variability are captured, especially in late-December to early-January
- High-resolution simulation winds exhibit eastward bias between 80-90 km, likely due to no parameterized gravity wave forcing

One of the major deficiencies in low-resolution WACCM(-X) (and other chemistry-climate models) simulations is the downward transport of NO following SSWs



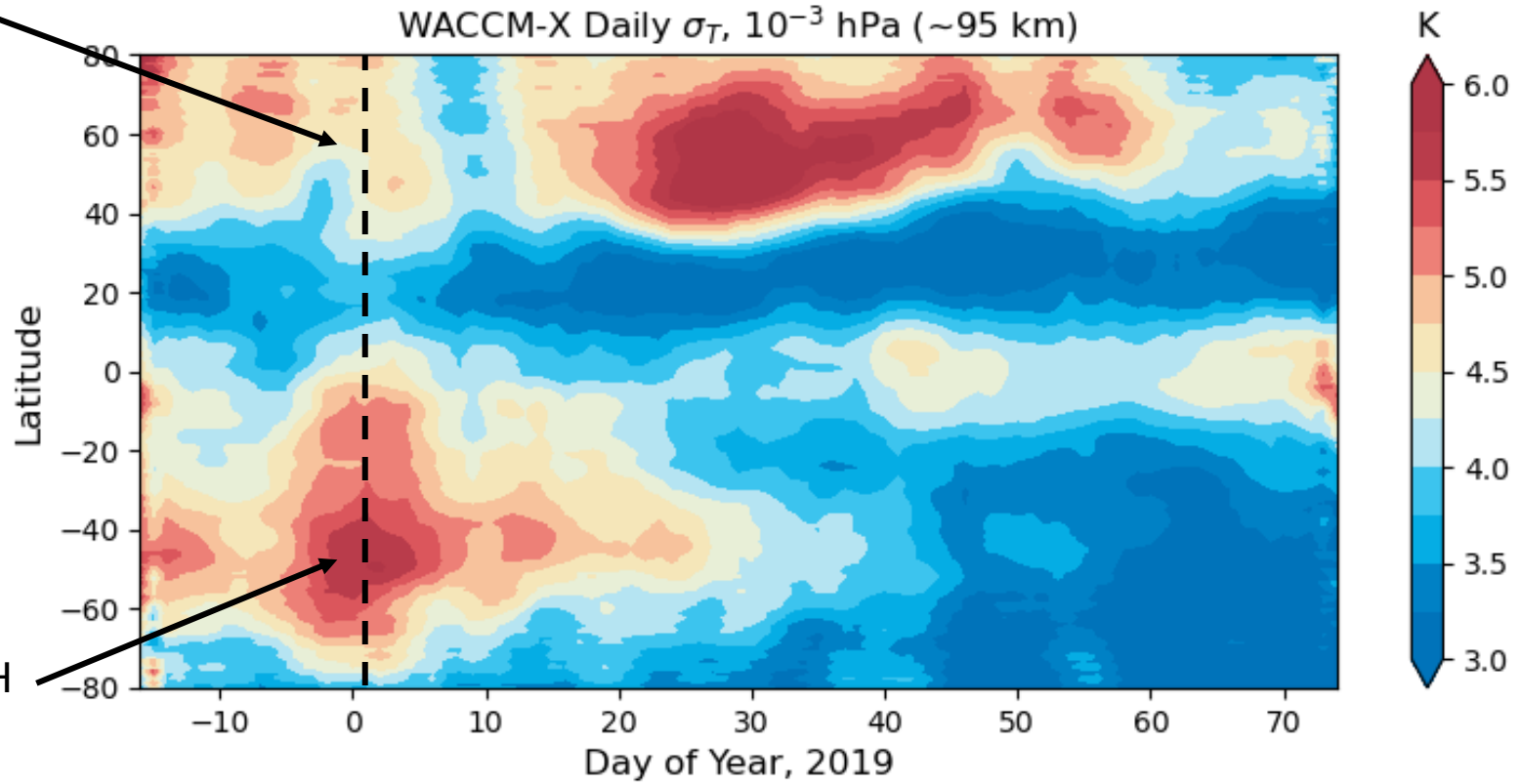
High-resolution simulation shows greater downward transport of NO, though it is still deficient in late-February to March



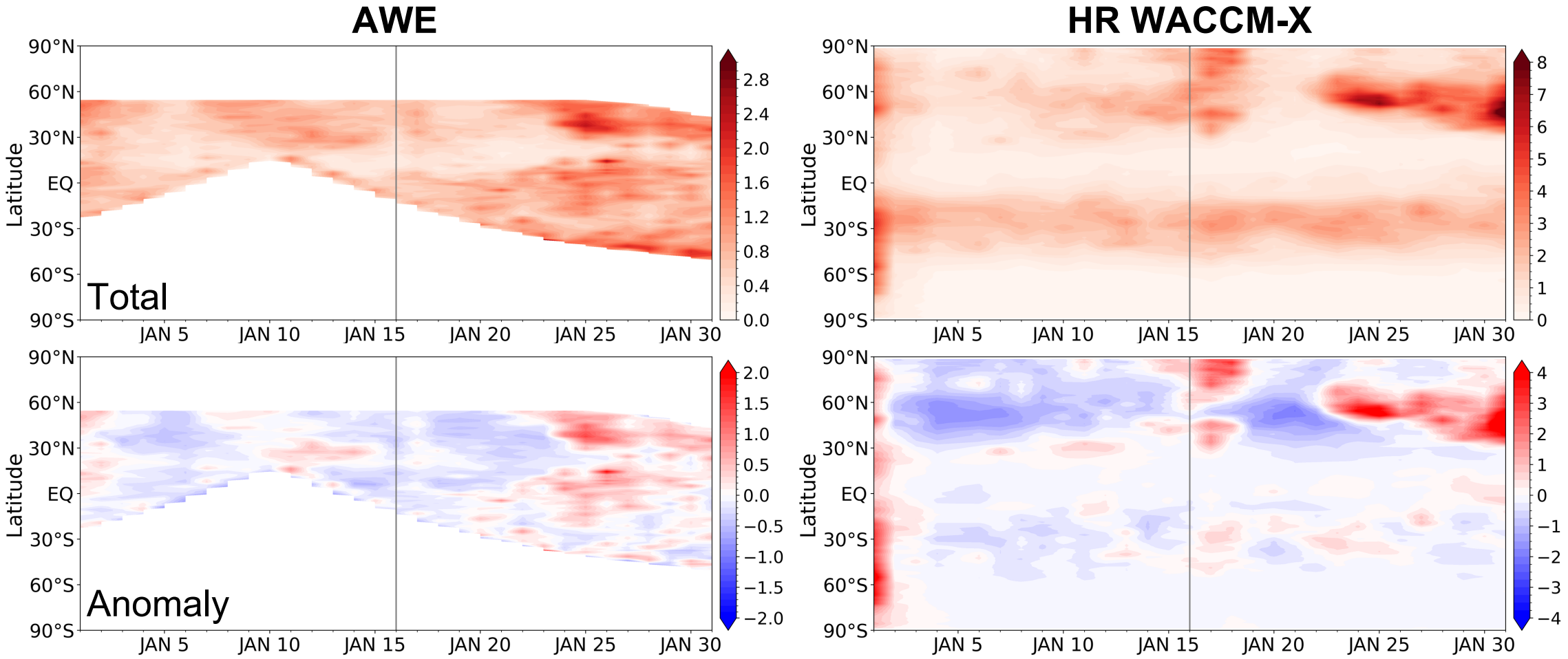
High resolution simulations show that there is a reduction in gravity wave activity during the SSW

Reduction in NH GWs

Increase in SH GWs (IHC?)

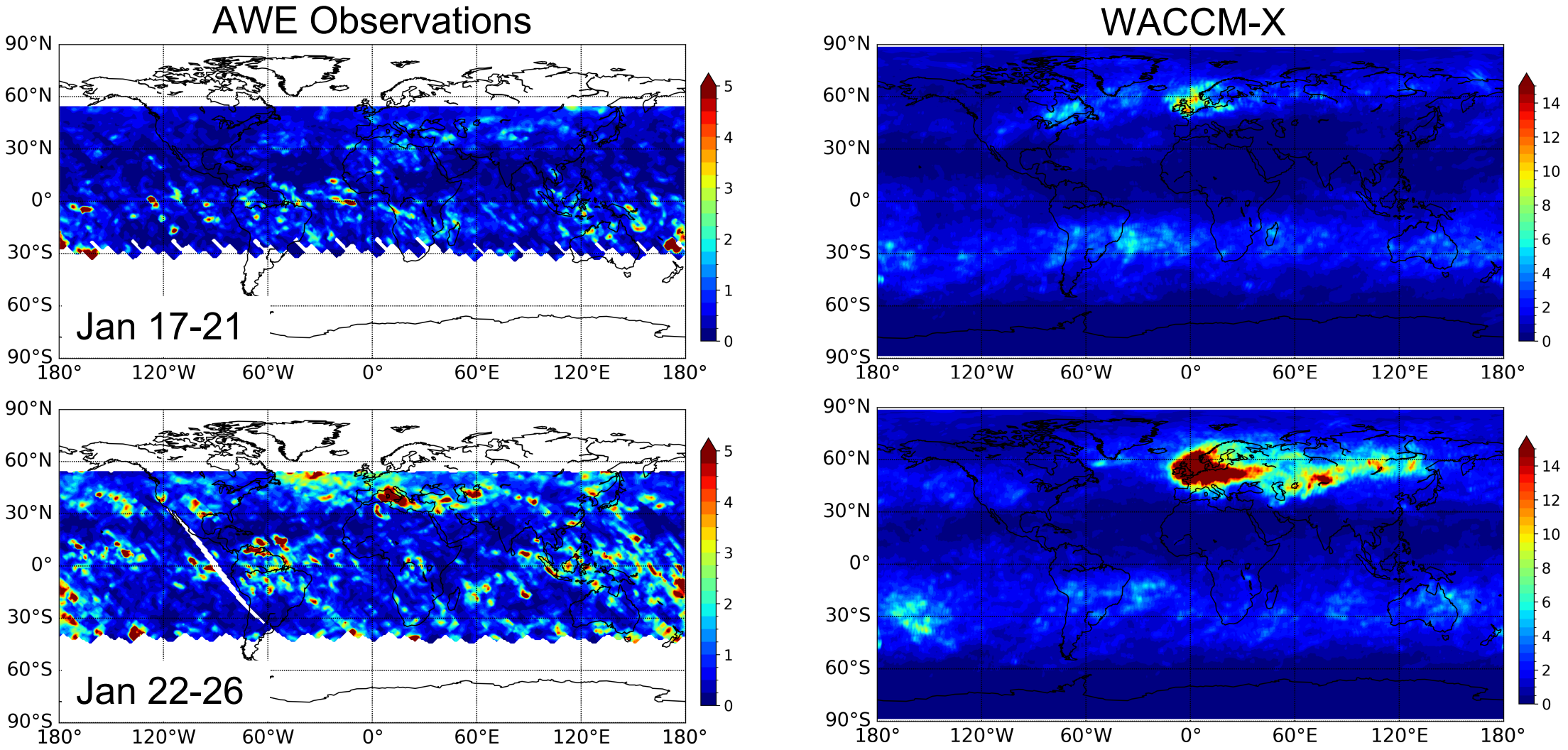


High-resolution simulations generally reproduce the observed mesospheric gravity wave variability during the 2024 SSW



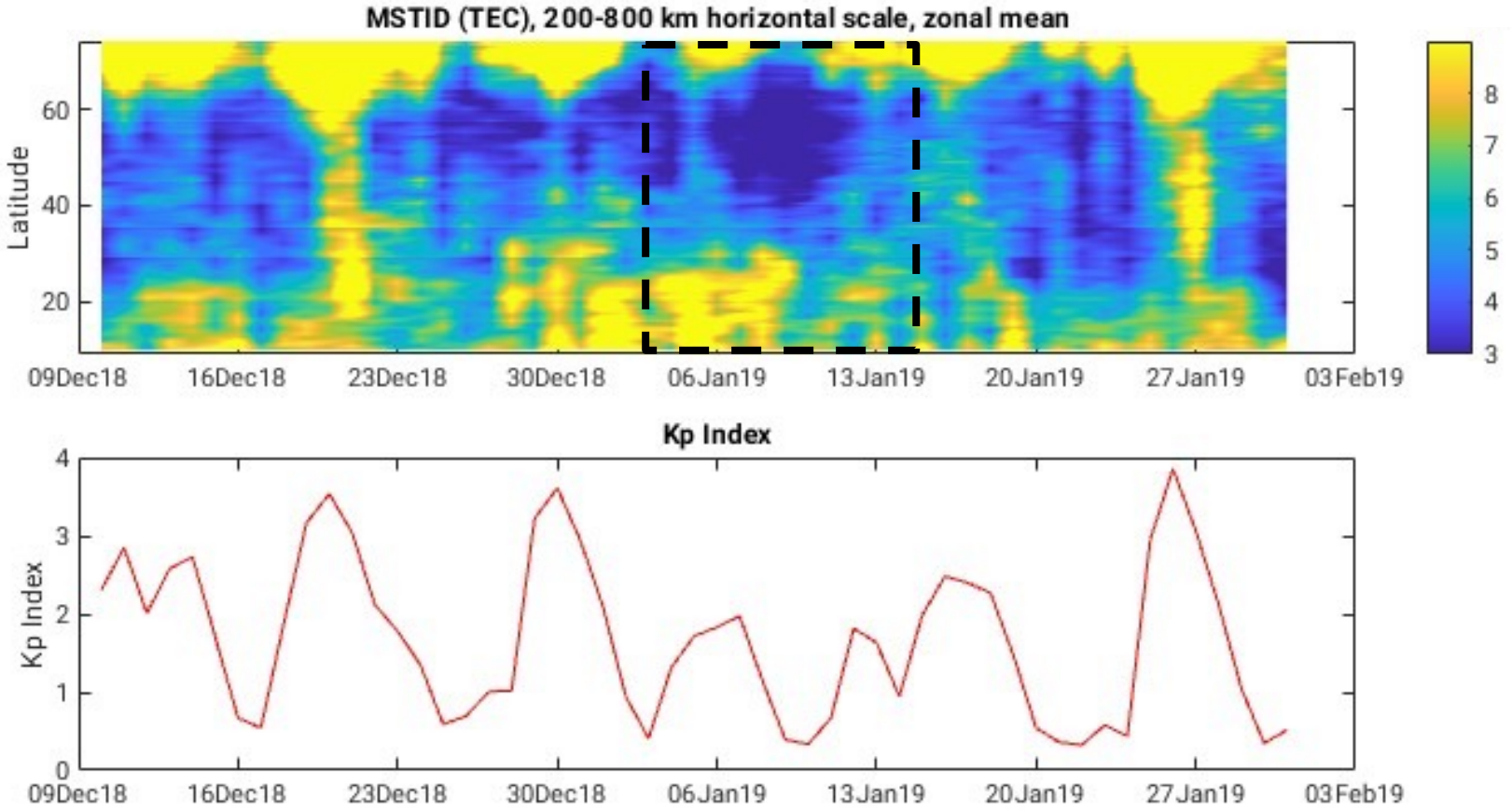
Results from Jiarong Zhang (USU) and Hanli Liu (HAO)

High-resolution simulations generally reproduce the observed mesospheric gravity wave variability during the 2024 SSW



Results from Jiarong Zhang (USU) and Hanli Liu (HAO)

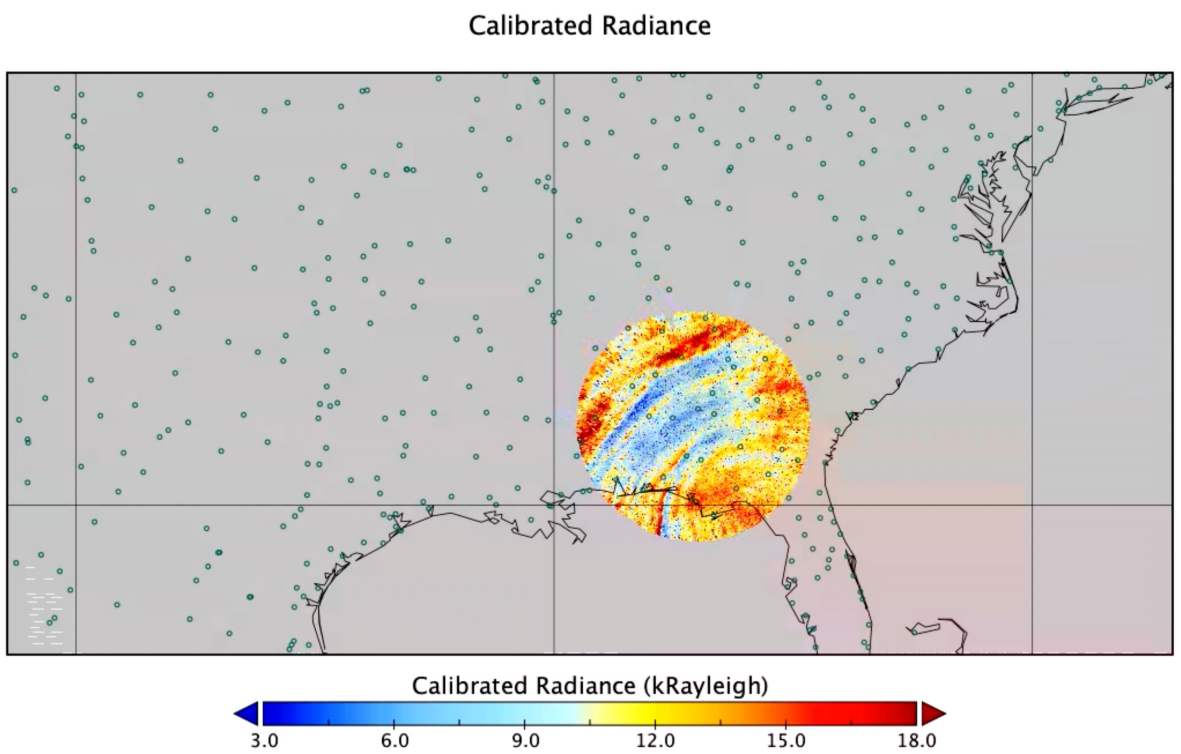
Reduction in gravity wave activity during the SSW also leads to a reduction in the small-scale variability in the ionosphere

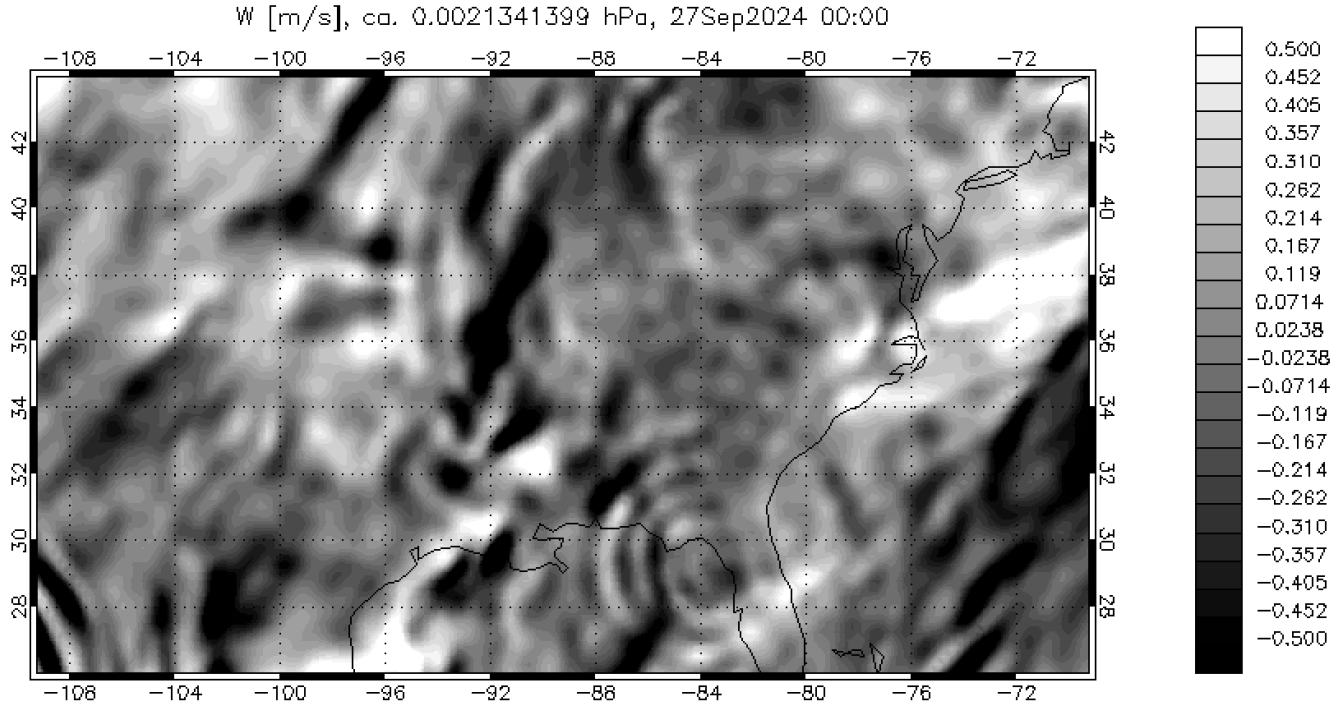


MSTID – Medium Scale Traveling Ionosphere Disturbances

Results from Komal Kumari (ASP/HAO)

Gravity wave simulations during Hurricane Helene





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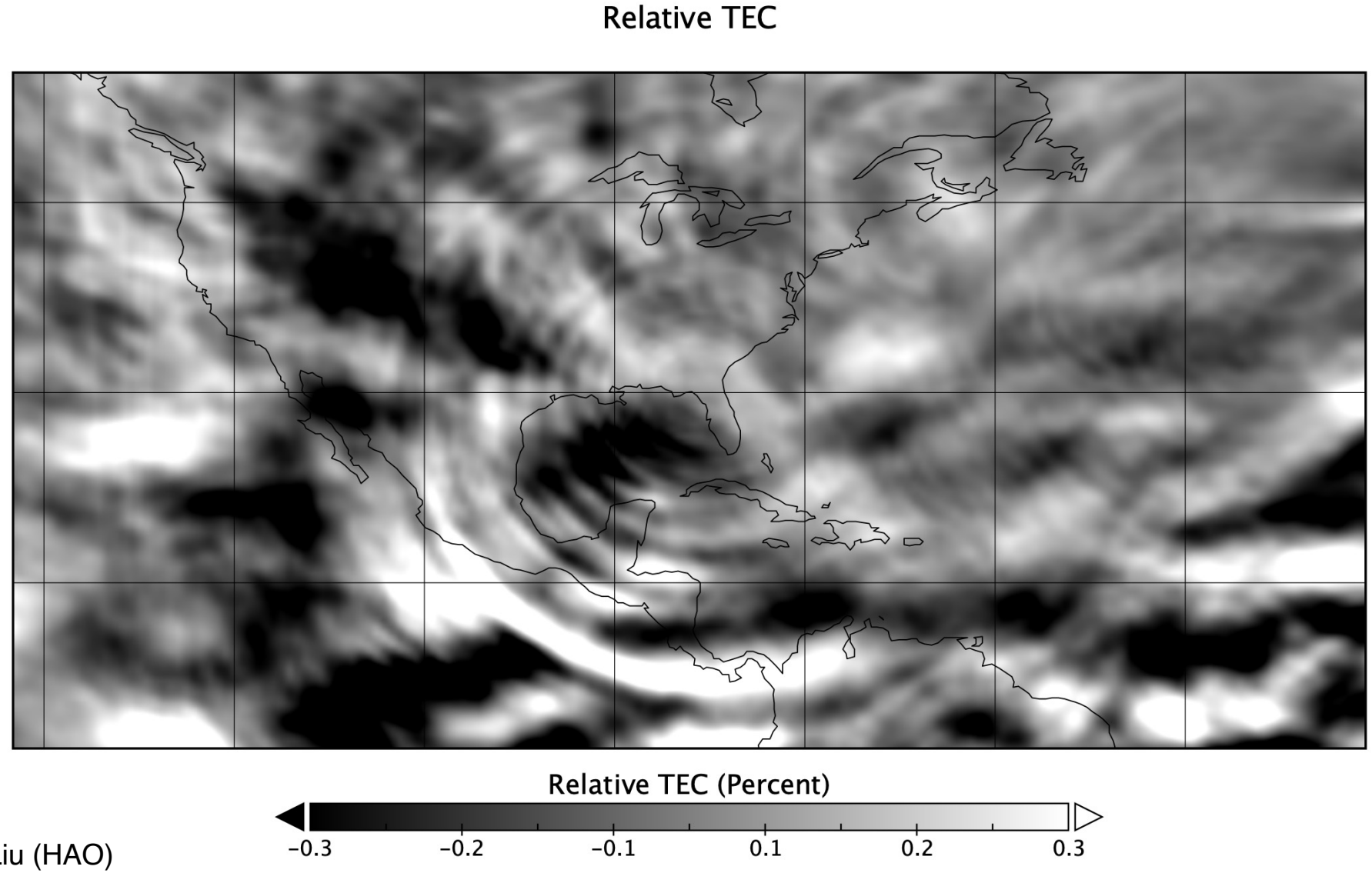
TEC Perturbation from Hurricane Helene from WACCM-X



September 27
UT 0245

Results from Hanli Liu (HAO)

Summary and Future Work

- Physics-side nudging has been implemented in high-resolution (ne120) WACCM-X.
- ERA-5 is recommended for nudging in order to best reproduce the wave spectrum across spatial scales.
- High-resolution nudged simulations are being used to support current (NASA AWE) and future satellite missions (ESA CAIRT, NASA DYNAMIC).
- Developed capability to use nudged high-resolution WACCM-X simulations as “nature run” for data assimilation observing system simulation experiments.