WAVECHASM: Small-scale waves, big implications – a regionally refined perspective with WACCM-RR

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Motivation

- It is likely that vertical transport in MLT is too slow in GCMs e.g. Whole Atmosphere Community Climate Model (WACCM) – missing transport due to unresolved gravity waves?
  - O, O_3 underestimated
  - T, Na and Fe are overestimated
- Gravity waves form due to atmospheric disturbances (storms, convection, flows over orography)
- Important small-scale gravity waves are not usually resolved, so parametrizations must be used (see e.g. Guarino et al. (2023))
- Global high-resolution models are too computationally expensive
- Using WACCM with regional refinement (WACCM-RR), it is now possible to resolve local regions whilst maintaining global coupling

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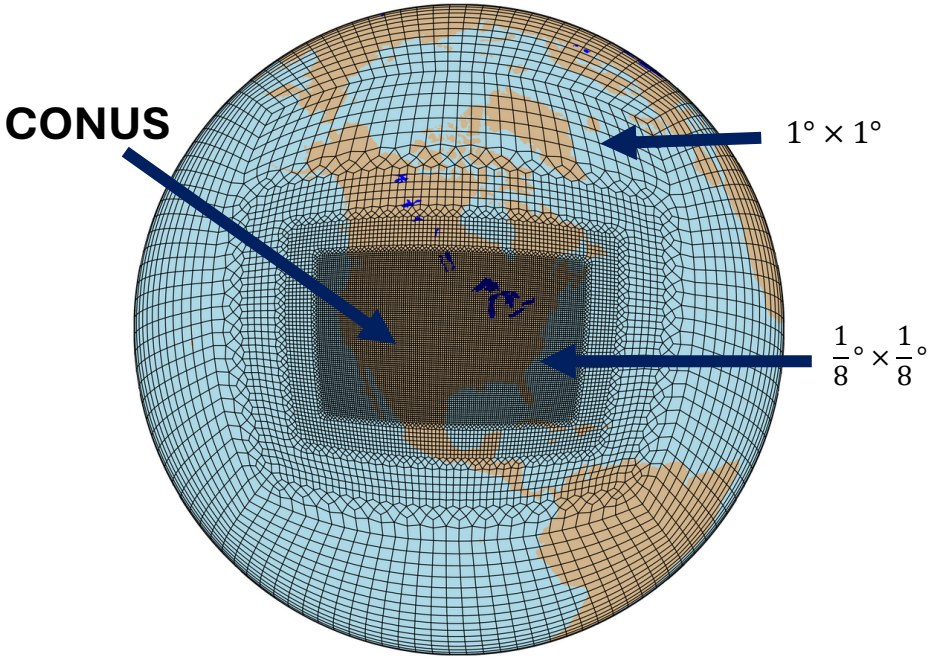
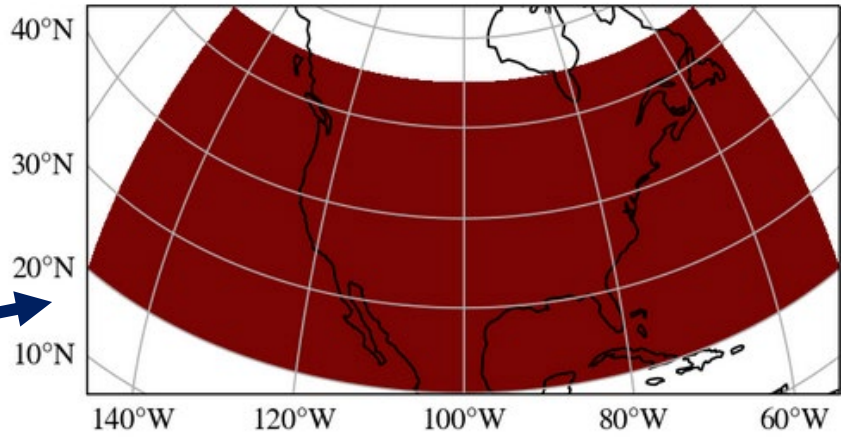
Experimental setup

	WACCM (Non-RR)	WACCM-RR (RR)
$\Delta x, \Delta y$	1° (111 km)	$\frac{1}{8}$° (14 km) over contiguous US 1° elsewhere
Δz (MLT)	2.5 – 3 km	2.5 – 3 km
Δt	30 min	3 min 45 seconds
λ_h cut-off	≈ 222 km	≈ 30 km
λ_z cut-off	≈ 6 km	≈ 6 km
t_{wave} cut-off	1 hour	7 min 30 seconds

Credit: Nick Davis, Peter Lauritzen, Daniel Marsh (NCAR)





- Free running historical atmosphere FWmaHIST **modelled for 2010**
- **Gravity wave drag scheme is turned off over extended CONUS domain in both models**

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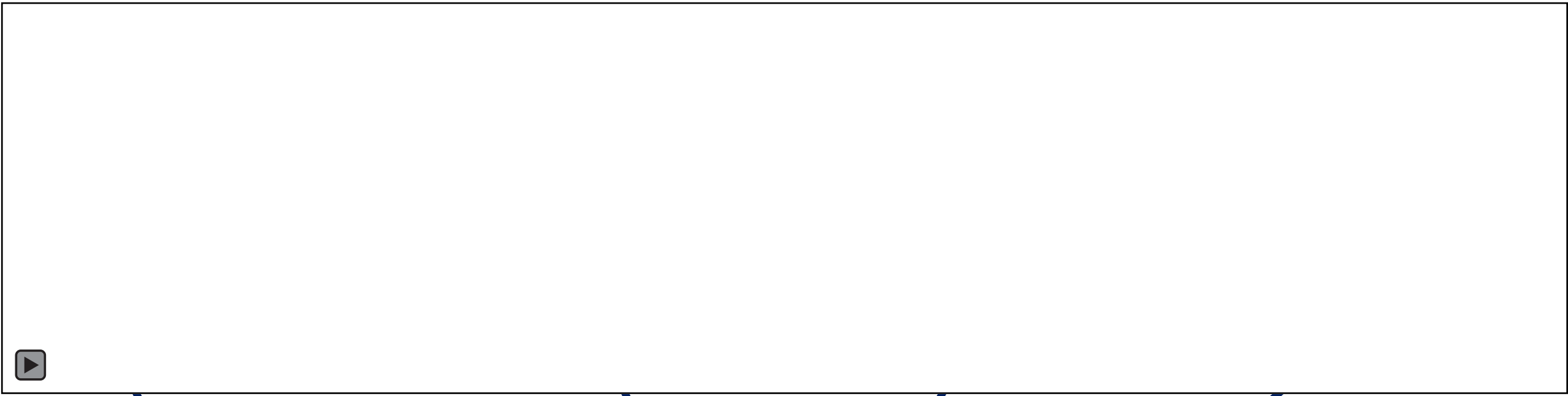
Temperature (K) 2010-06-01/02 over extended CONUS domain

~110 km ~85 km ~40 km ~8 km

Non-RR



RR

RR generally hotter than Non-RR

Large spectrum of concentric gravity waves

Higher temperature spots are seen to appear

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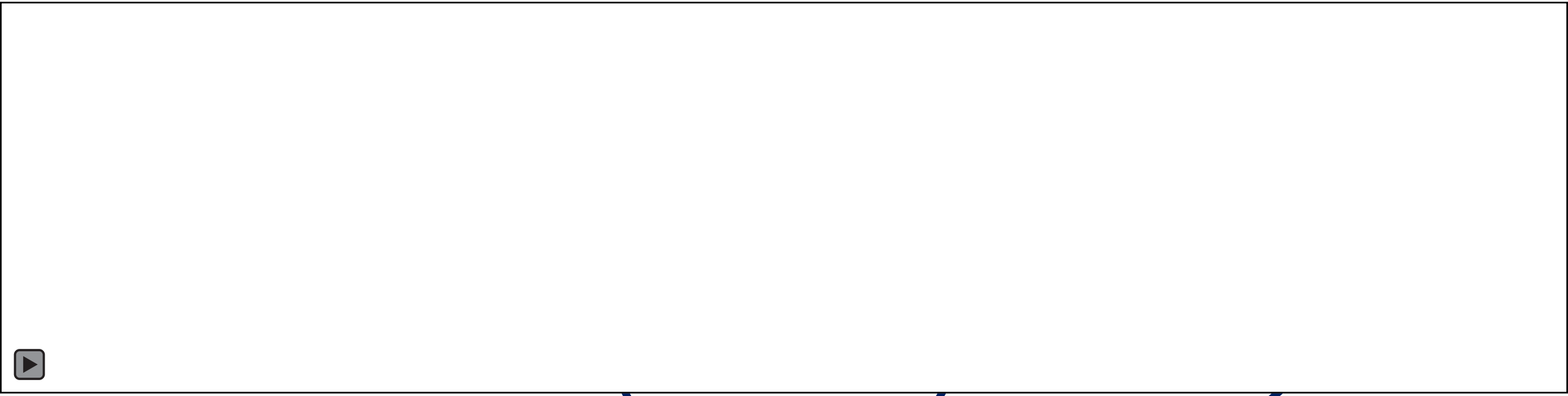
Vertical velocity (ms^{-1}) 2010-06-01/02 over extended CONUS domain

~110 km ~85 km ~40 km ~8 km

Non-RR



RR

Large spectrum of concentric gravity waves

Spots with large upward vertical velocities

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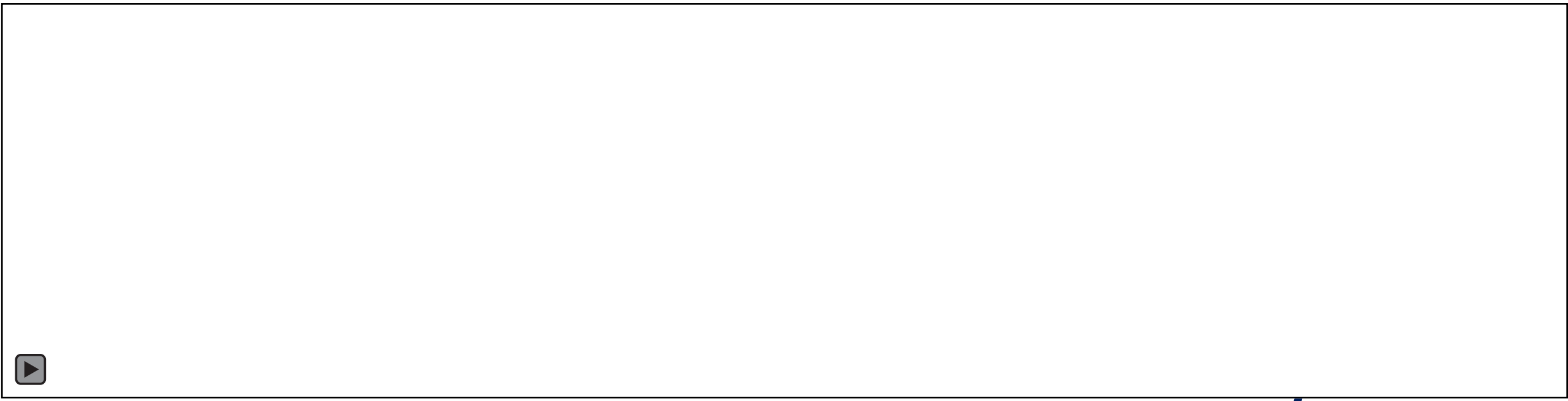
Nitric Oxide $\log_{10}$(vmr) 2010-06-01/02 over extended CONUS domain

~110 km ~85 km ~40 km ~8 km

Non-RR



RR

Lightning NOx associated with strong convection

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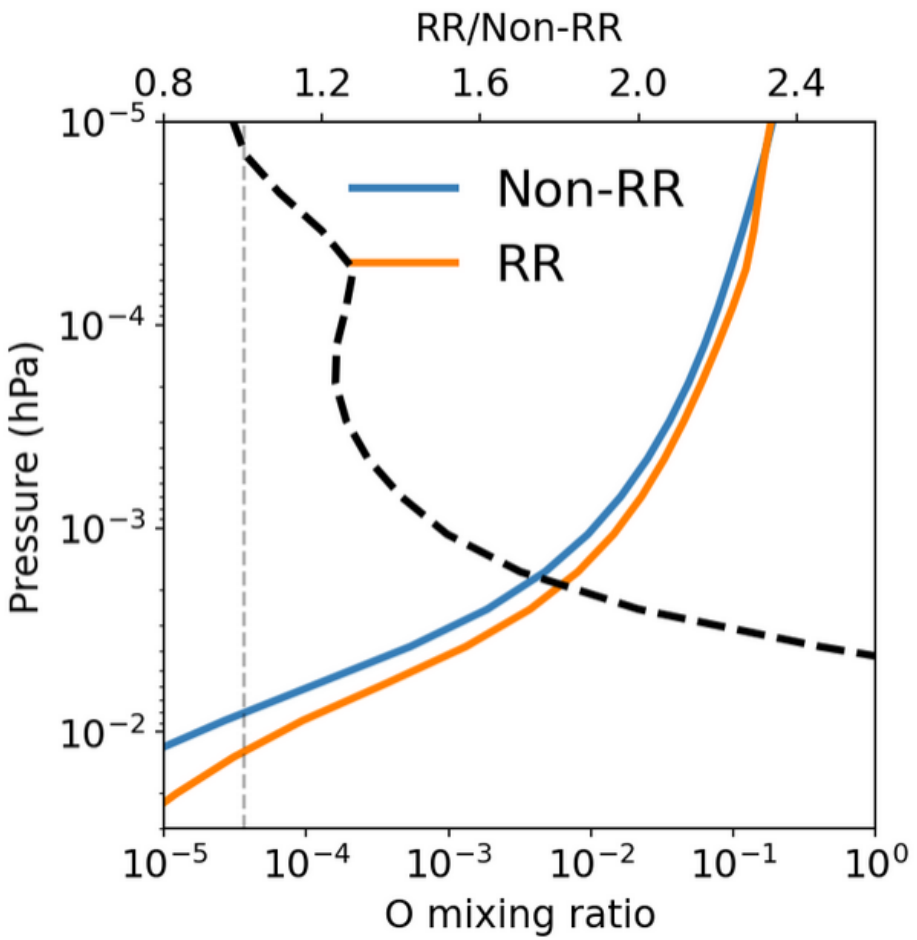
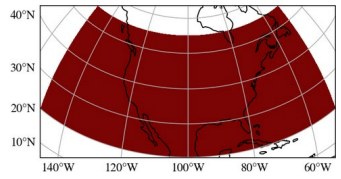
Odd Oxygen vmr, ~ 75 – 130 km, June monthly mean, domain mean

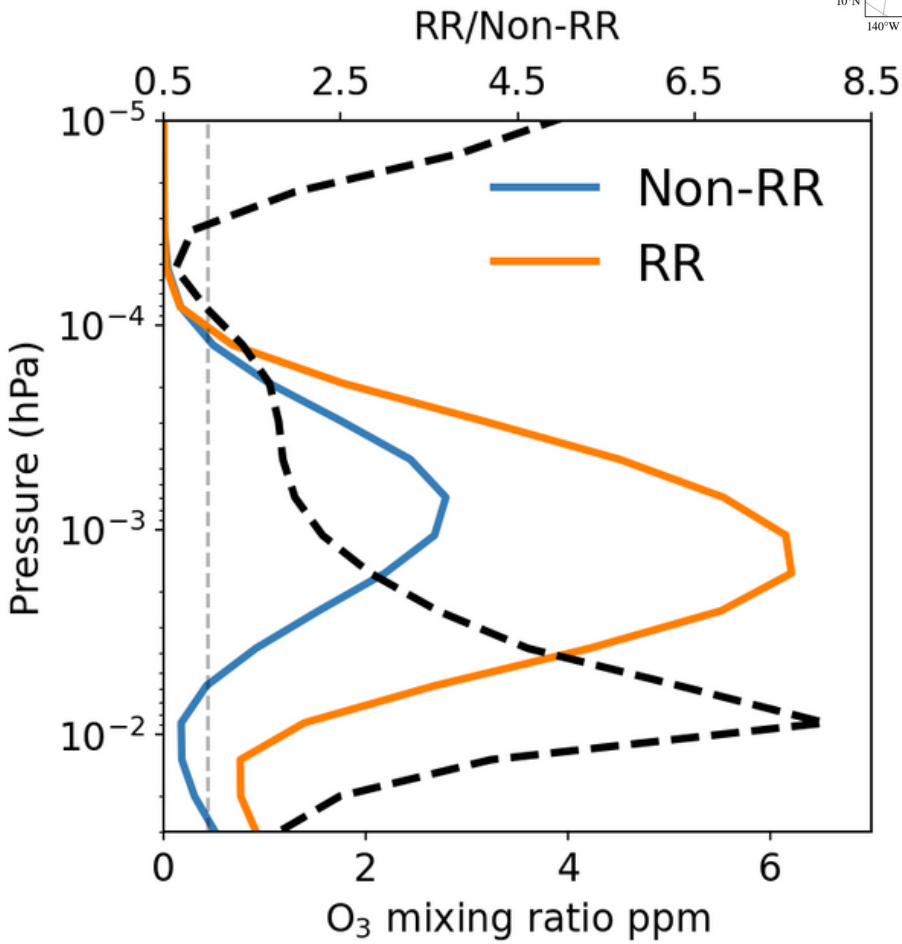
O vmr



- Atomic oxygen increases throughout MLT

Night-time O3 vmr ppm





- More than doubling of night-time O_3 at secondary maximum

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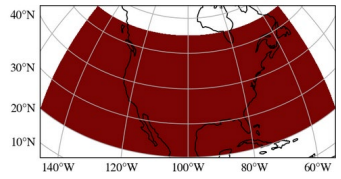
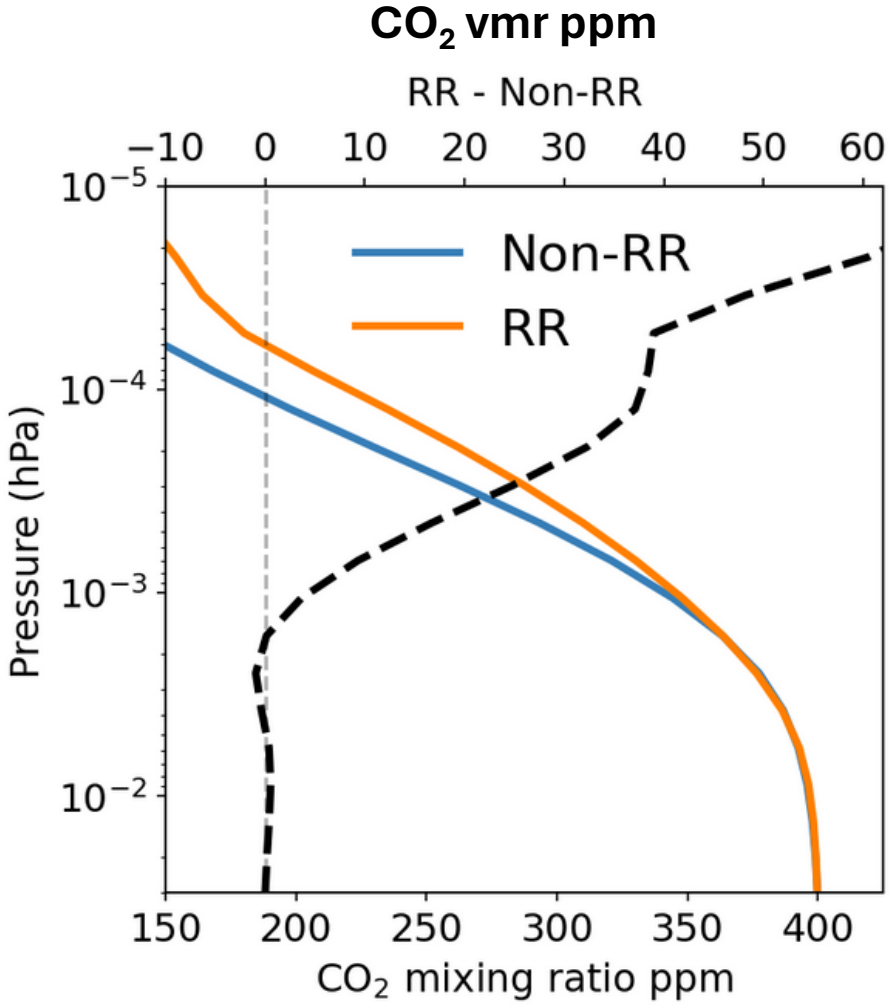
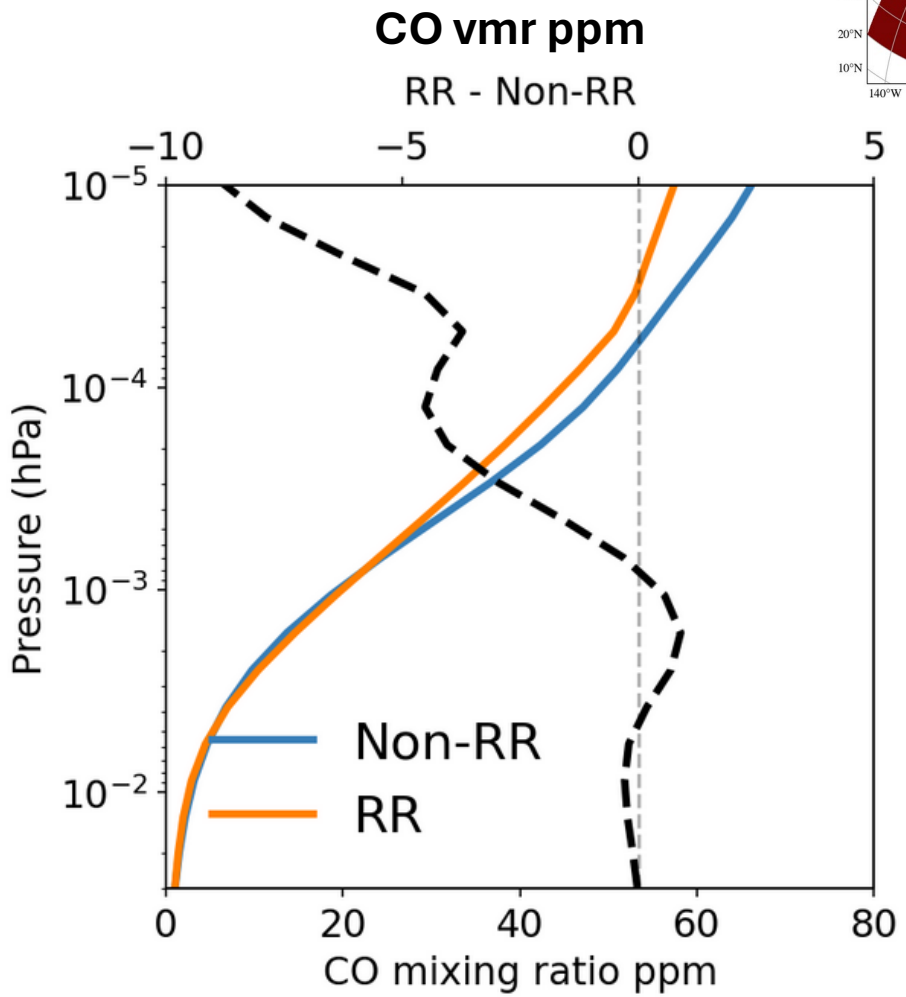
CO_2, CO vmr, ~ 75 – 130 km, June monthly mean, domain mean







- CO_2 increases above ~ 90 km
- CO decreases above ~ 95 km

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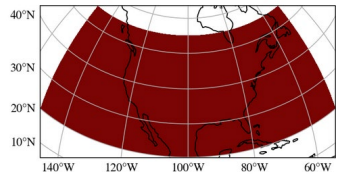
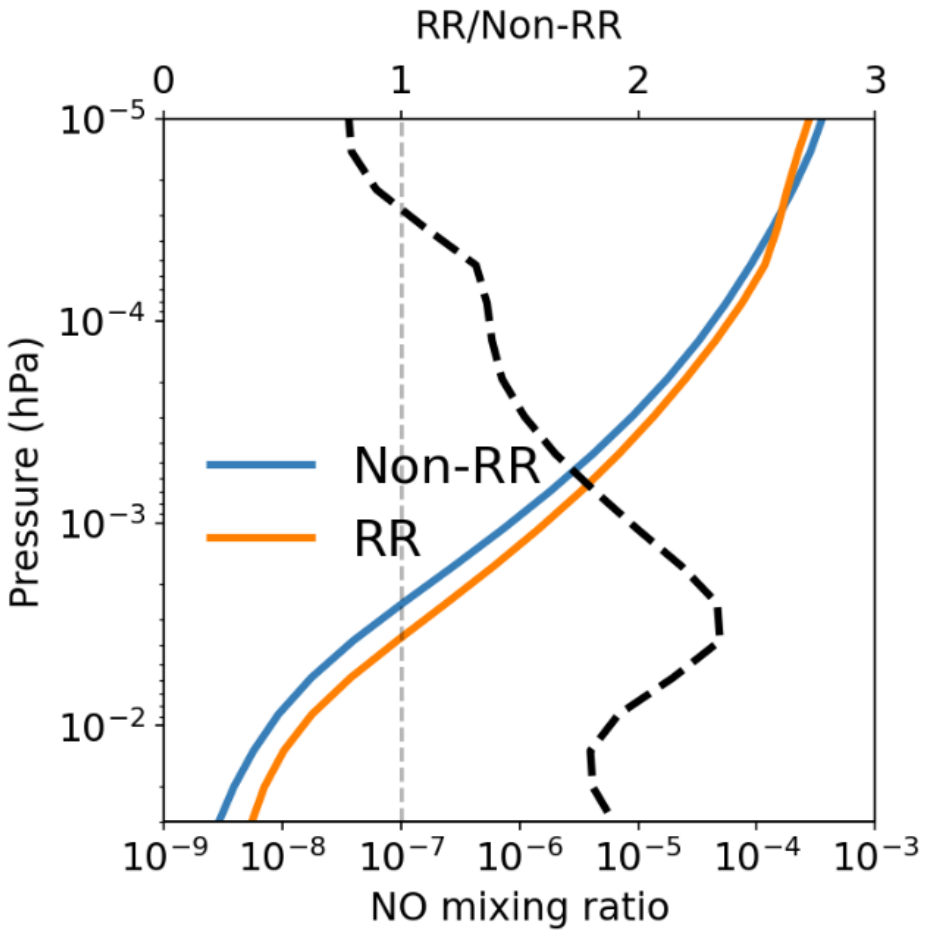
NO vmr, T (K), ~ 75 – 130 km, June monthly mean, domain mean

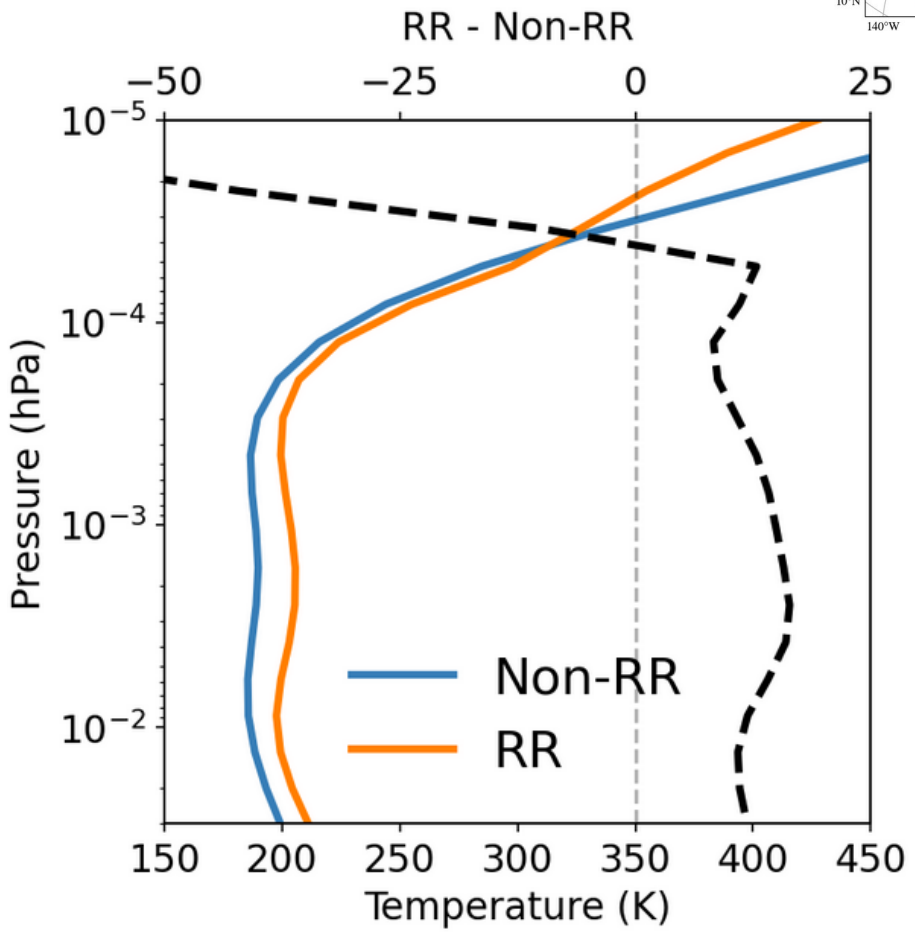


NO vmr



- NO ~ doubled in mesosphere, surplus decreases with height

Temperature (K)



- T surplus in mesosphere, sharp increasing deficit above ~ 125 km

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Summary

- **Unresolved gravity waves are usually parametrized**, recent work has improved WACCM performance (see Guarino et al. (2023))
- **WACCM-RR can resolve smaller-scale waves** down to as far as ~ 10 km horizontal wavelengths, ~ 6km vertical wavelengths and ~ 8-minute periods
- Two models, **WACCM (Non-RR)** and **WACCM-RR (RR)** were studied
- **A significant amount of wave activity is resolved in RR** and observed in various fields such as T, w, NO
- Clear link between small-scale variability between lower and upper atmosphere
- **O_x increases**
- **CO_2 increases and CO decreases in lower thermosphere**
- **Going forward:** quantify contribution to model differences due to gravity waves

Thank you

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