MUSICA
Multiscale Infrastructure for Chemistry and Aerosols

Modeling multiscale chemistry and aerosols associated with convective transport in the Asian Summer Monsoon

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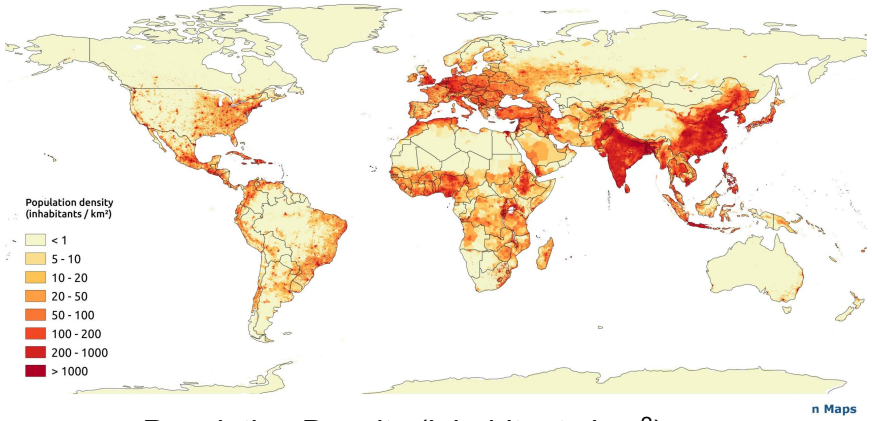
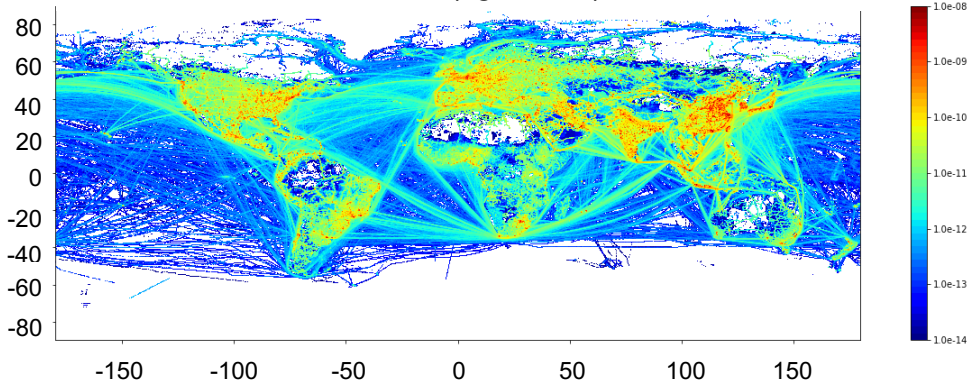
Background

- The Asian Summer Monsoon (ASM) is important for weather, climate, air quality and atmospheric composition with its location over a large densely-populated area that extends throughout South to Southeast and East Asia.



Population Density (inhabitants km^{-2}),
From https://worldinmaps.com/world/population-and-settlement/population-density

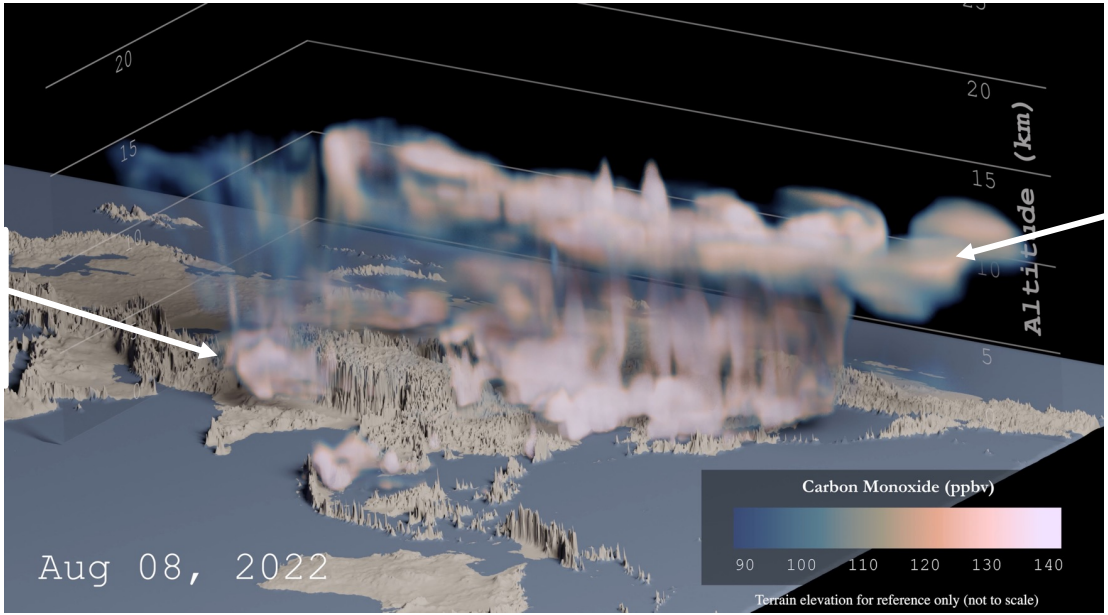
CAMS NO_x Emissions (kg m^{-2} s^{-1}), 2021-08-21



Background

- Deep convection associated with the ASM lofts pollutants from urban and biomass burning source regions to the upper troposphere, where an enhancement of these pollutants accumulate in the associated upper tropospheric anticyclone.

CO emitted from urban regions



CO accumulating in UT anticyclone

3-d rendering of modeled CO (ppbv) for 8 August 2022

Background

- With local-scale processes such as urban emissions and deep convection connected to continental-scale impacts in the upper troposphere, it is a challenge to accurately model explicitly the critical multiscale processes with traditional chemistry transport models.

Frontier Science Studies Require a New Modeling Infrastructure

- A new class of modeling infrastructure, which has variable sized grid meshes, allows for such representation.
- The Multiscale Infrastructure for Chemistry and Aerosols (MUSICA) will facilitate the use of a variety of chemistry schemes, physics parameterizations and atmospheric models

MUSICA: Multiscale Infrastructure for Chemistry and Aerosols

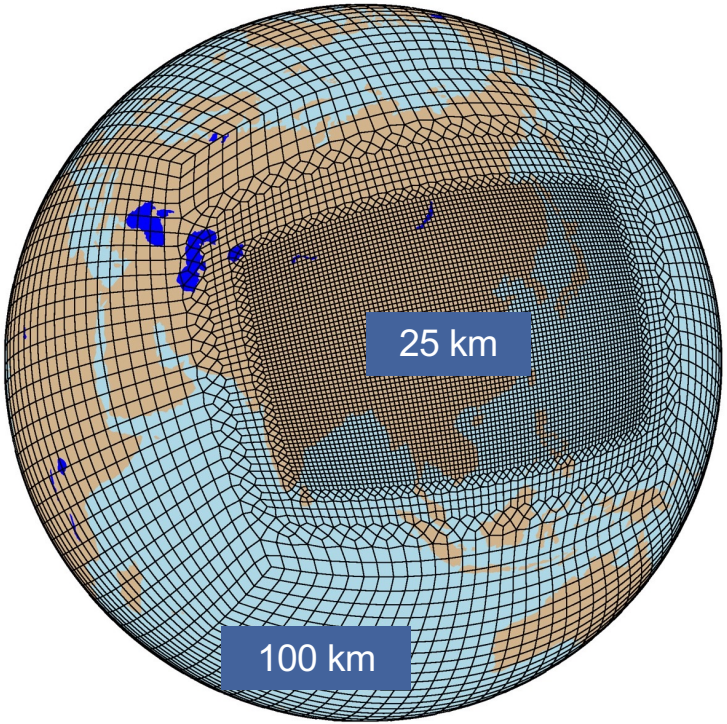
A new modeling infrastructure that will facilitate the use of a variety of chemistry schemes, physics parameterizations and atmospheric models

1. Developing infrastructure, refactoring code to create model independent chemistry modules
2. Testing, evaluating, and applying variable resolution grid meshes with atmospheric chemistry in a global model

- *Illustrate capabilities of applying variable resolution grid meshes in the context of the Asian Summer Monsoon*

New Grid Meshes Allow for Regional Refinement

Spectral Element (cubed sphere) uses a hydrostatic advection scheme



Voronoi mesh (mostly hexagons) in MPAS uses a non-hydrostatic advection scheme

Model Prediction Across Scales (MPAS)

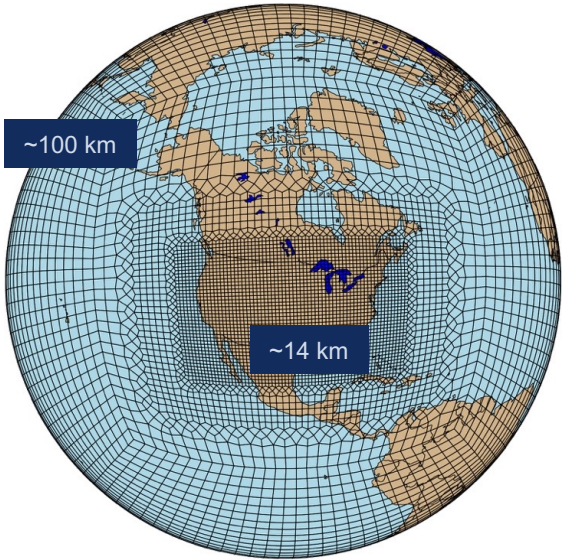
Benefits and Challenges of Grid Meshes With Regional Refinement

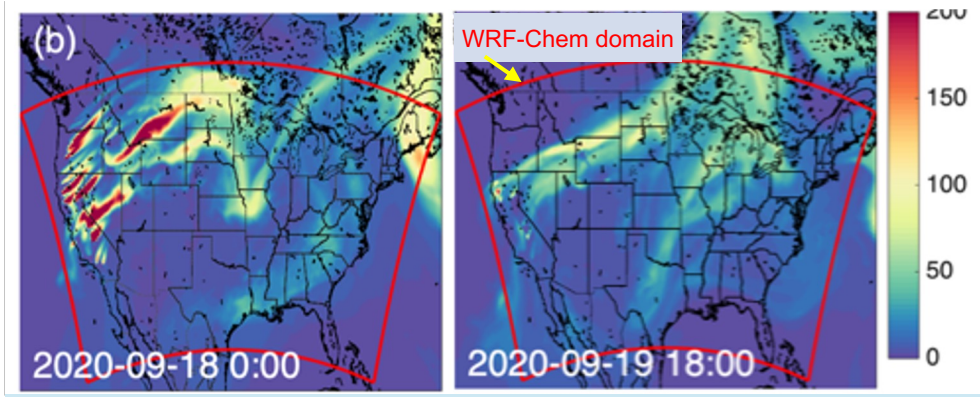
Benefits:

- At finer resolution, emissions and chemistry are more accurately represented
- Pollutants are simulated on human exposure-relevant scales
- Global feedbacks are directly included

Challenges:

- Determining if the physics and chemistry parameterizations work well with variable resolution grid meshes
  - dust, sea-salt, lightning NO_x emissions
- Most of the grid points are in the refined region
  - ➢ Computational cost is similar to WRF-Chem





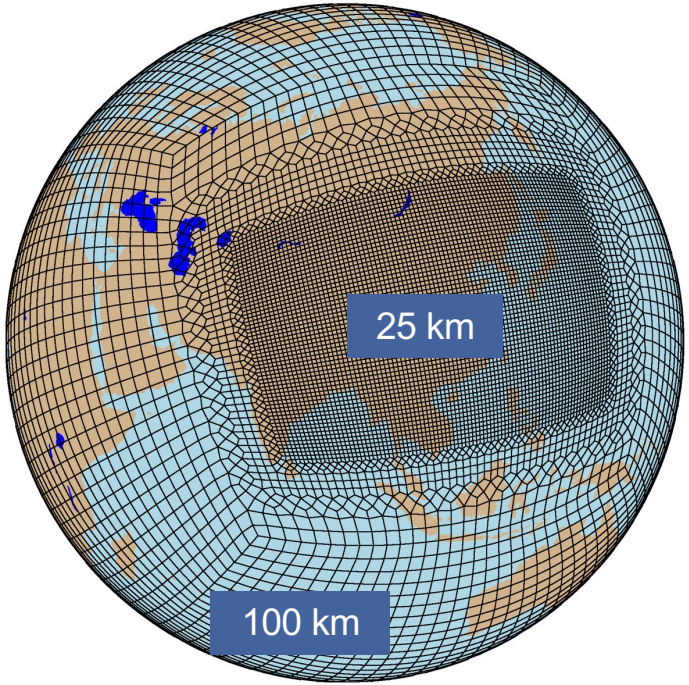
Fire plumes simulated in global model with regional refinement get transported outside of, and back into, the WRF-Chem domain

Wenfu Tang et al., JGR, 2023

New Grid Meshes Allow for Regional Refinement

MUSICAv0

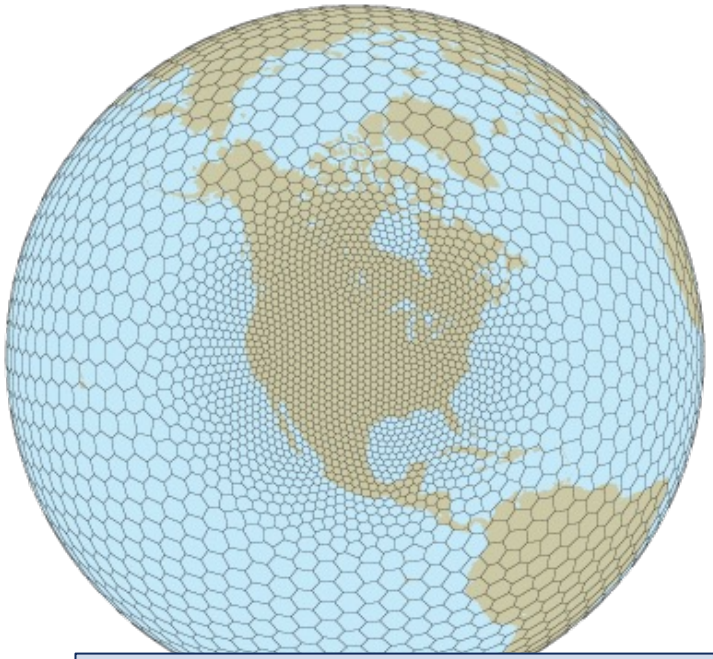
Tropospheric and Stratospheric Chemistry (TS1) using the Spectral Element grid mesh



MUSICAv0 is available within CESM

Upcoming: MUSICAv1

Tropospheric and Stratospheric Chemistry (TS1) using the MPAS grid mesh



Why should we move to the MPAS grid mesh?

MUSICAv0 to MUSICAv1

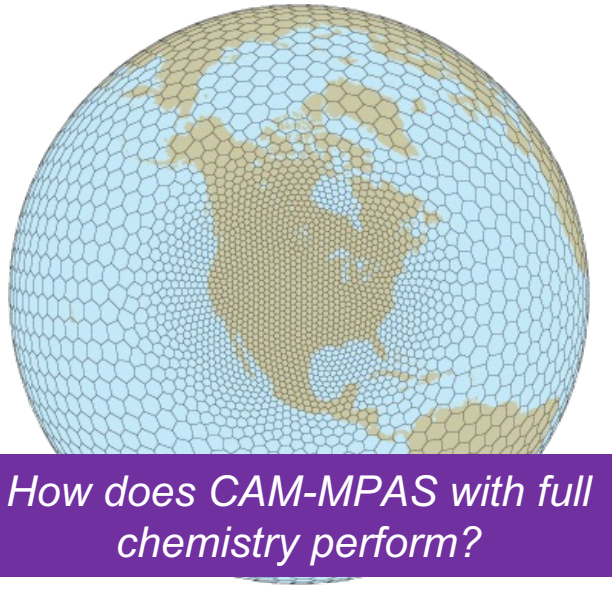
MUSICAv0 covers the global to regional scale

- That is grid spacings down to ~10 km
- Many regional chemistry transport models like WRF-Chem use these grid spacings for air quality research

➢ There's a lot that can be addressed with MUSICAv0

However,

- With a hydrostatic dynamical core, it is not appropriate to use MUSICAv0 at grid spacings < 5 km
- MUSICAv1 will employ the MPAS non-hydrostatic dynamical core so that we can investigate local-scale processes such as convection



How does CAM-MPAS with full chemistry perform?

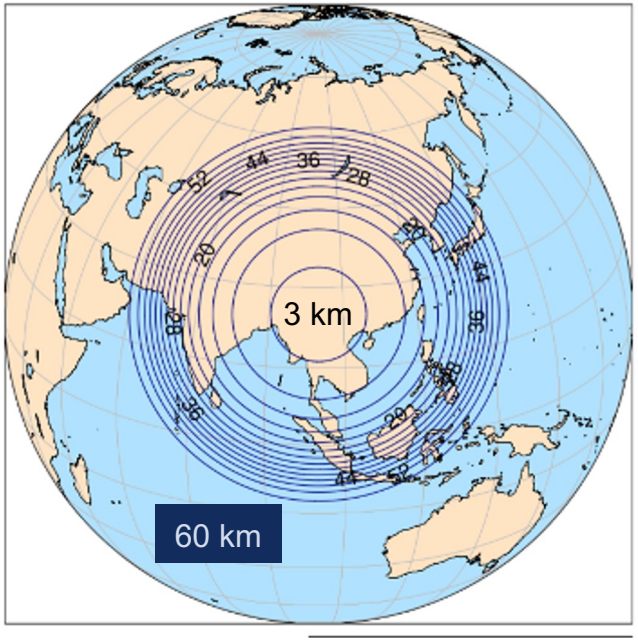
Tests of CAM-MPAS with full chemistry

Asian Summer Monsoon

- Grid mesh centered over SE Asia
- 60 - 3 km grid mesh (840,000 columns)
- Troposphere-Stratosphere (TS1) chemistry (168 trace gases & aerosols)

Emissions: CAMS 0.1deg emissions inventory

Case study: 23-28 August 2021

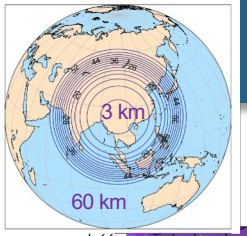


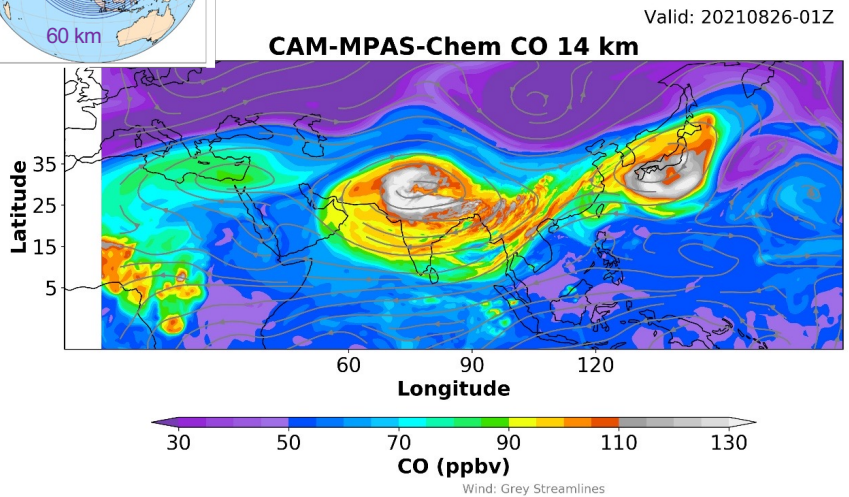
Preliminary Results are reasonable

Next Steps:

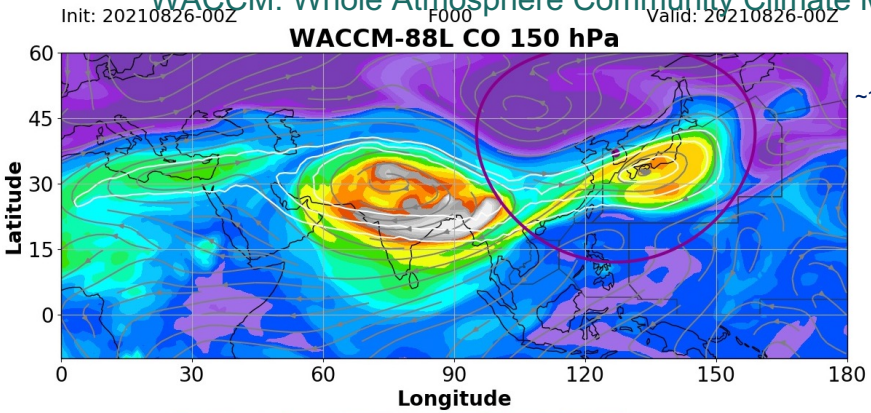
- Further comparisons with CAM-MPAS-chemistry on a uniform grid
- Test computational aspects

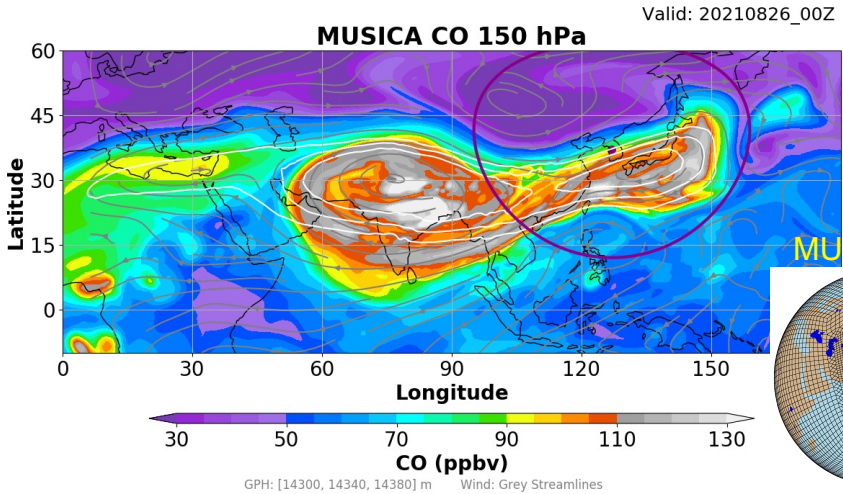
Upper Troposphere CO (τ ~ 1 month)





WACCM: Whole Atmosphere Community Climate Model





- CAM-MPAS-Chem: 60km to 3km, 32 levels, free running, instantaneous
- WACCM: 1deg, 88 levels, nudged, instantaneous
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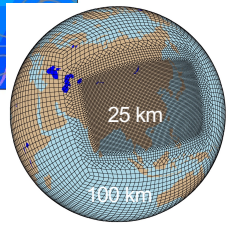
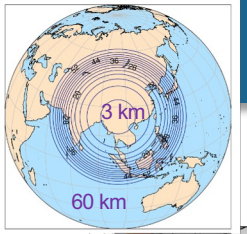
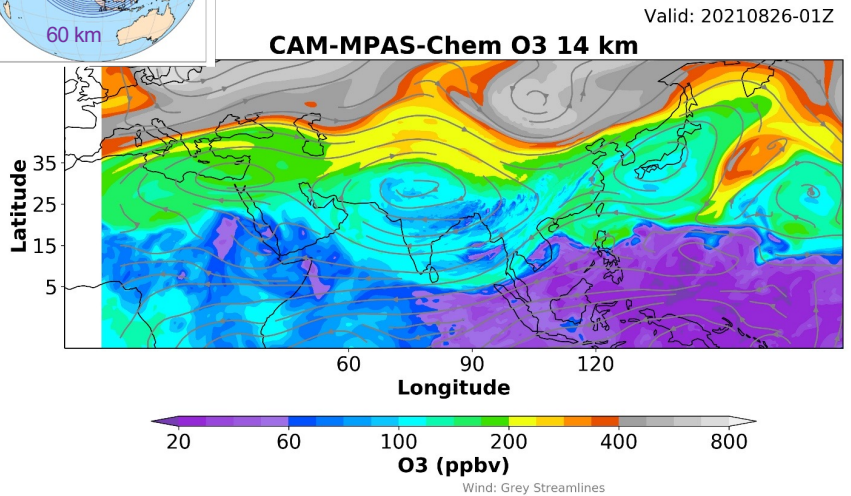
MUSICAv0



Upper Troposphere O_3 (τ < 1 month)





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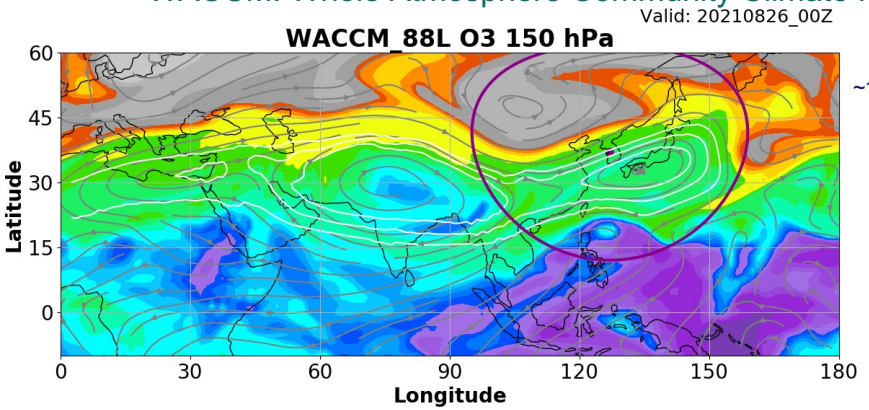

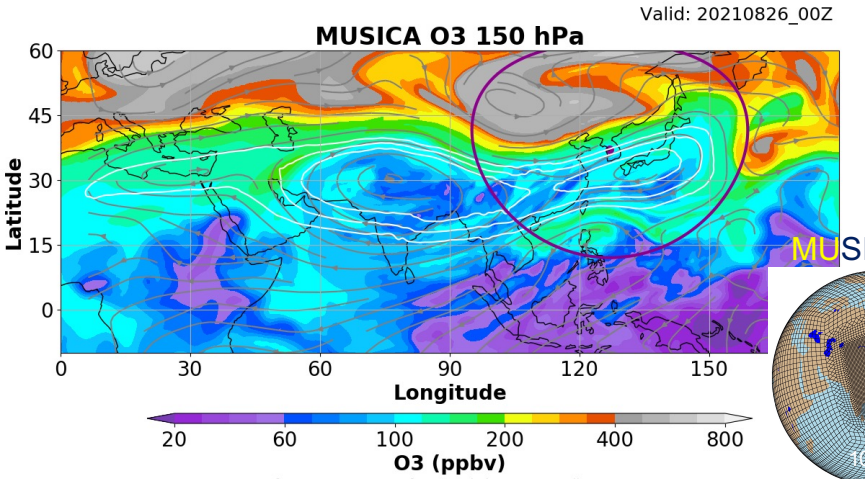

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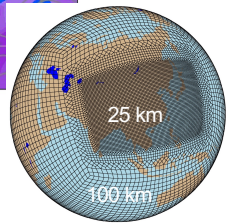
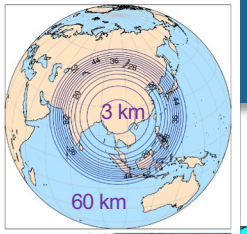
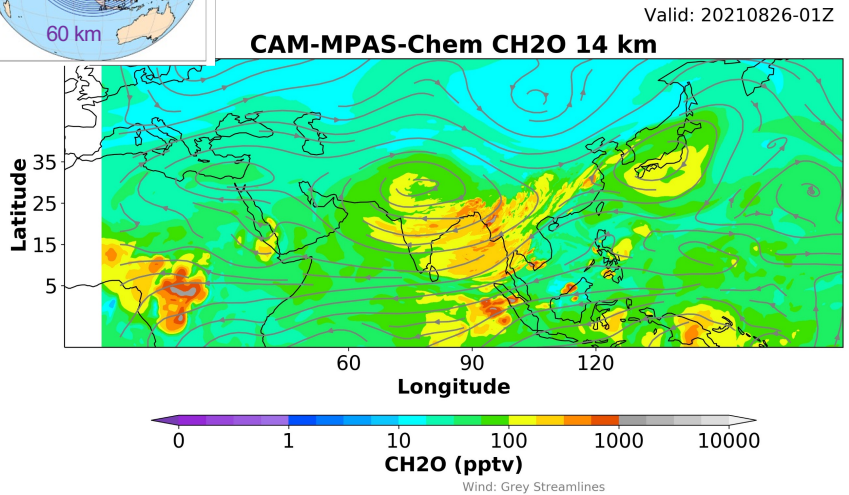
MUSICAv0



Upper Troposphere CH_2O (τ < 1 day)





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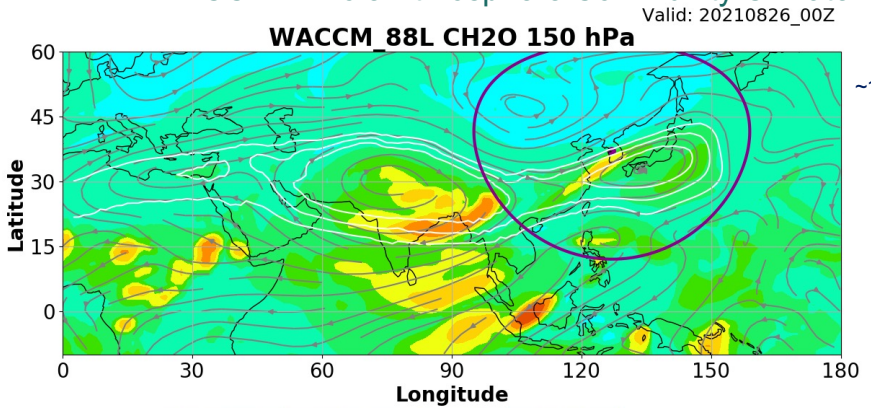
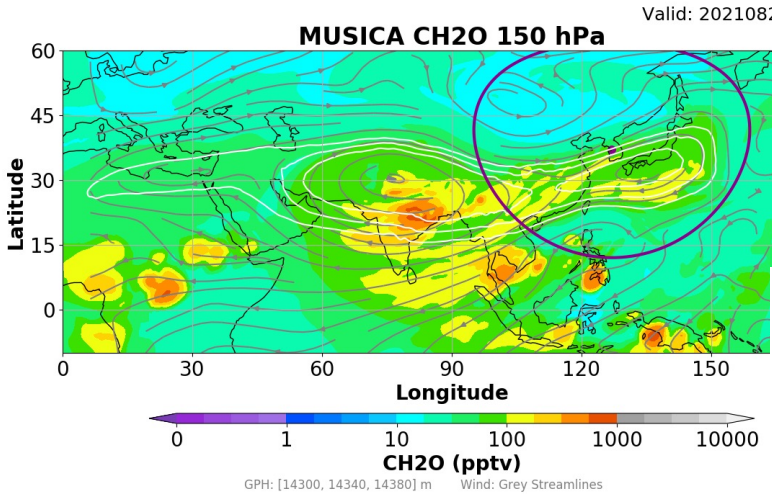
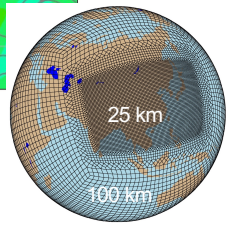
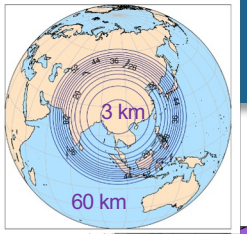


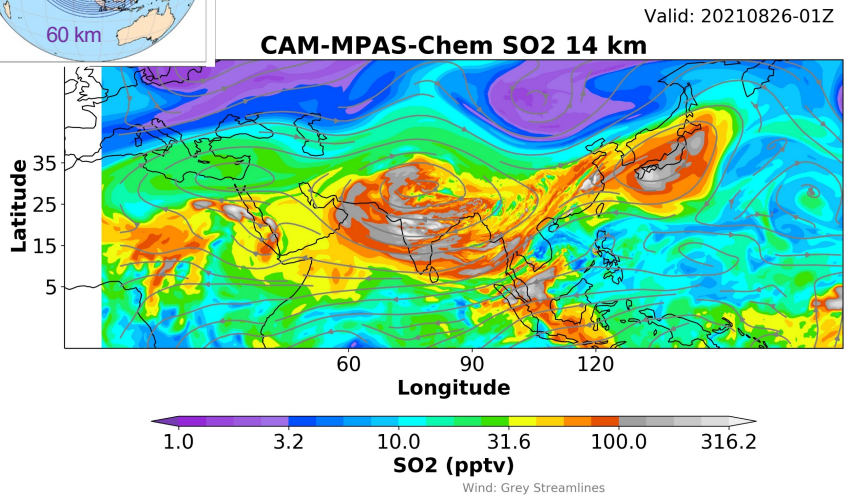


MUSICAv0



Upper Troposphere SO_2 (τ < 1 day)





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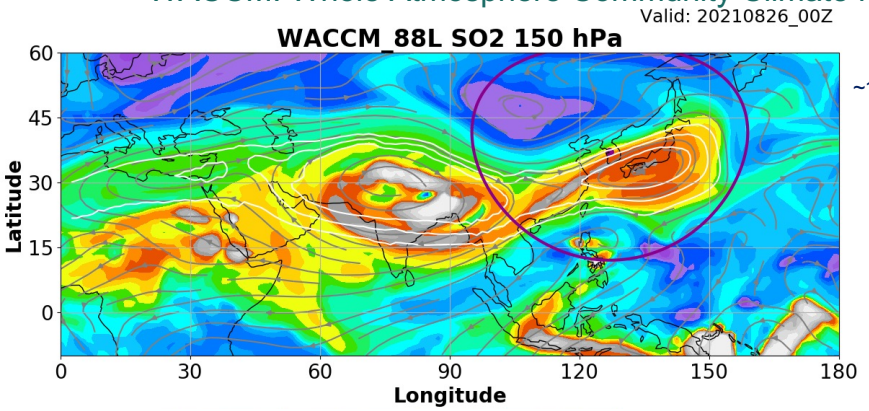
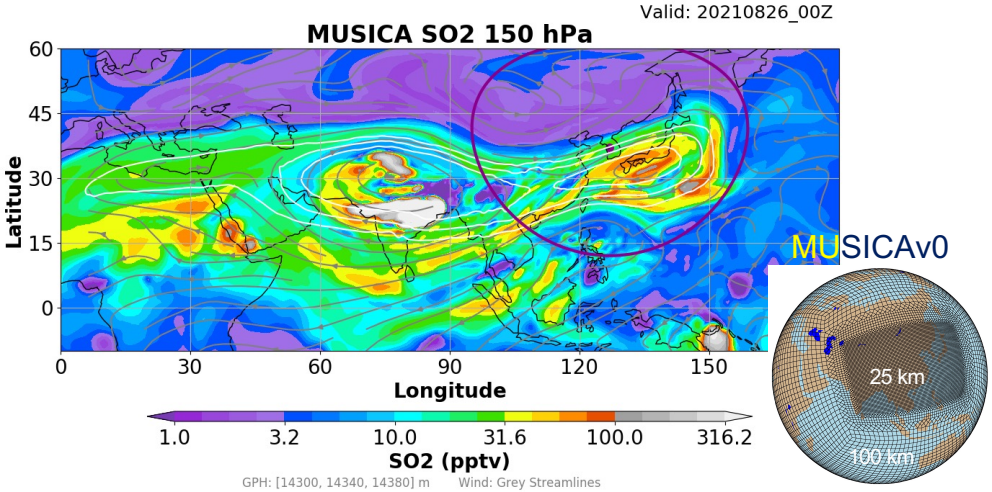
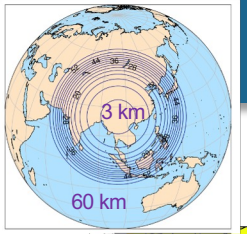
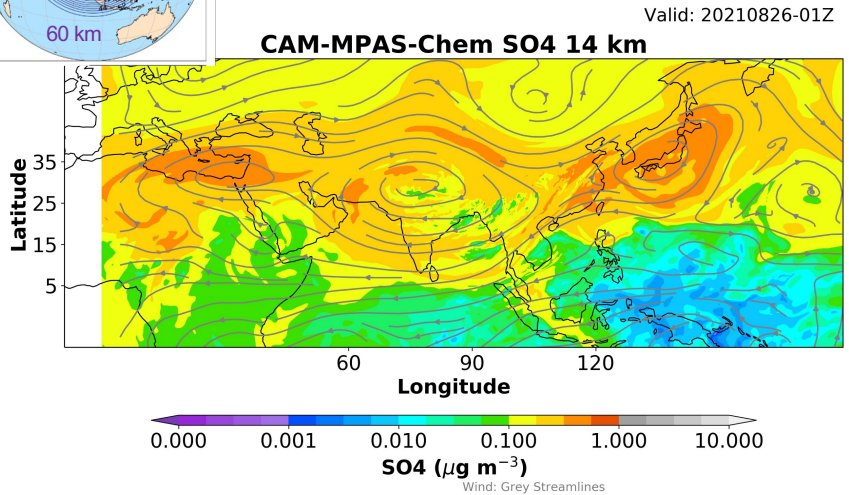




MUSICAv0

Upper Troposphere Aerosol Sulfate (τ ~3-4 days)





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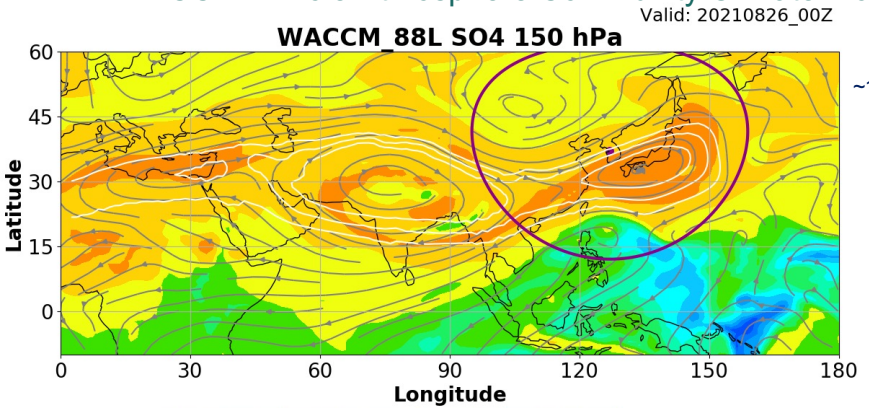

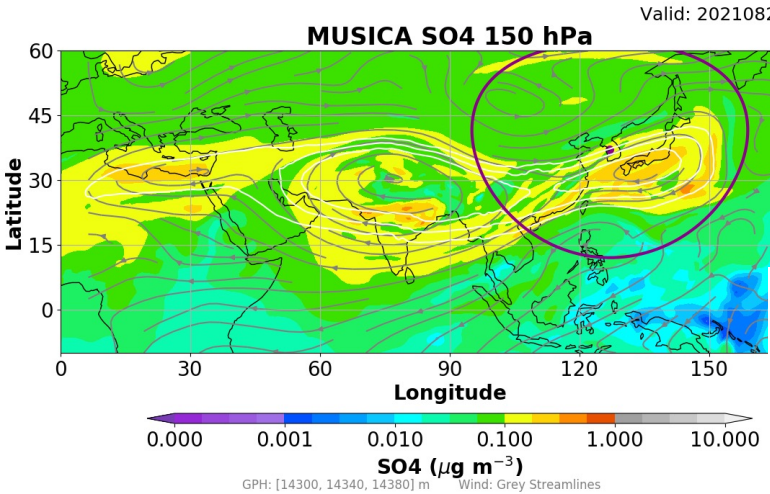

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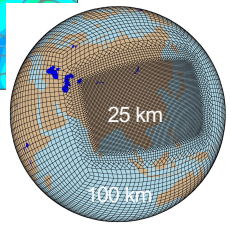
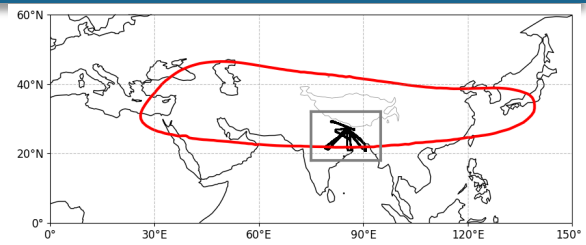
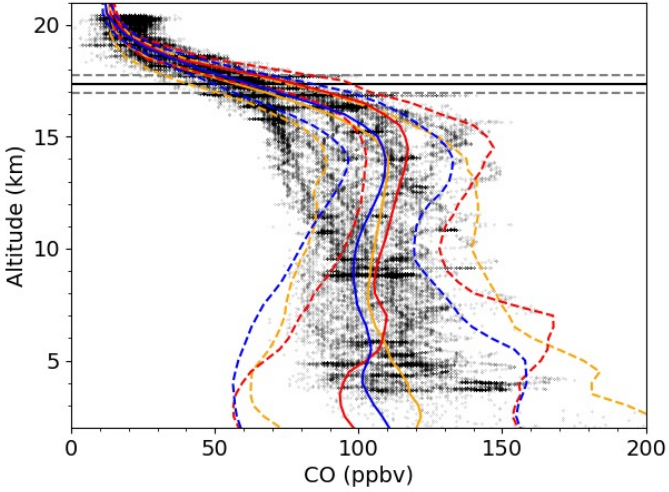


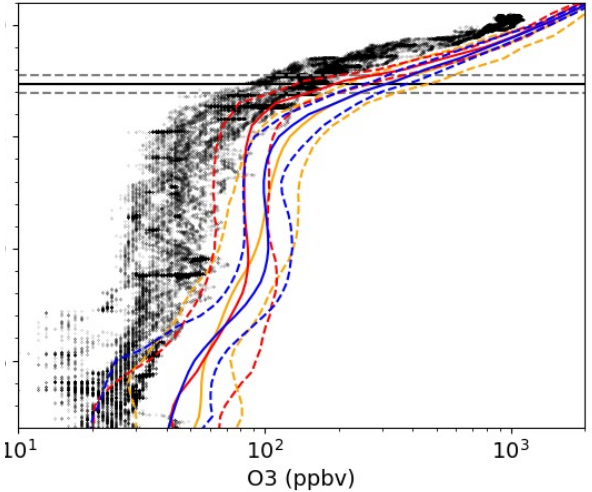
Vertical Profiles in Context of StratoClim Observations



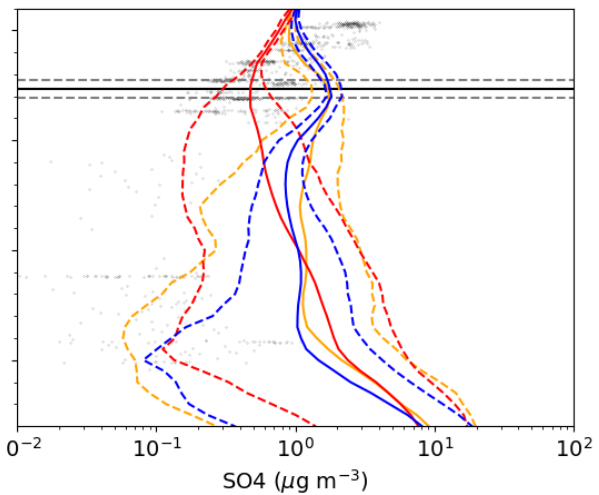
- StratoClim Observations: *27 July – 10 August 2017*
- CAM-MPAS-Chem: 60km to 3km, 32 levels: *23-28 August 2021*
- WACCM: 1deg, 88 levels: *23-28 August 2021*
- MUSICAv0: 1deg to 0.25deg, 32 levels: *23-28 August 2021*



CO and aerosol sulfate have similar averages and ranges for both models and observations



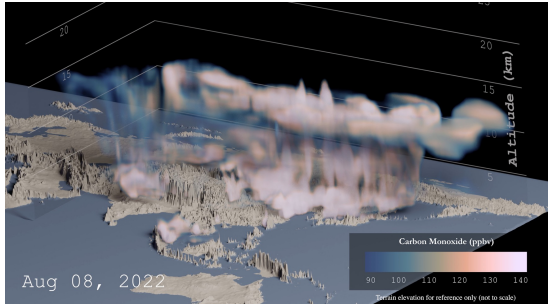
All models have a high bias for O_3 throughout troposphere



CAM-MPAS-Chem results look reasonable from surface to lower stratosphere

Addressing Local-to-Global Science Questions with MUSICA

- With local-scale processes such as urban emissions and deep convection connected to continental-scale impacts in the upper troposphere, it is a challenge to accurately model explicitly the critical multiscale processes with traditional chemistry transport models.



Frontier Science Studies Require a New Modeling Infrastructure

- MUSICA with the MPAS dynamical core provides the capability to model global to local scales
  - Evaluation of CAM-MPAS-chemistry for the Asian Summer Monsoon region shows reasonable results,
  - Continue to evaluate and test its capabilities
- There are several other science applications that would benefit from global to regional to local grid meshes

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Thank you!

MUSICA web page: