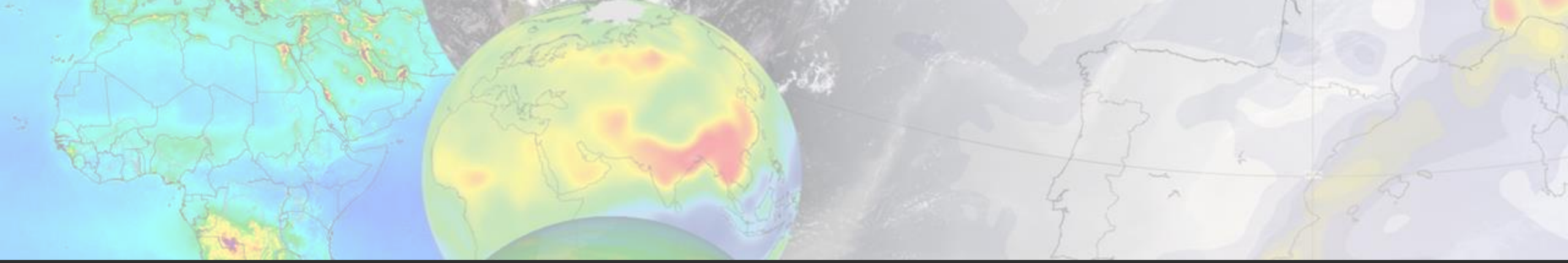

Simulating Local Air Quality in a Global Model with MUSICAv0: Multi-scale Infrastructure for Chemistry and Aerosols

Louisa Emmons & The MUSICA Team

Atmospheric Chemistry Observations and Modeling (ACOM) Laboratory

National Center for Atmospheric Research

Boulder, CO USA

20 September 2024

MUSICA
Multiscale Infrastructure for Chemistry and Aerosols

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MUSICA is the next generation atmospheric chemistry modeling approach at NCAR

The MUSICA project is giving the capability to provide model independent chemistry modules to any atmosphere model

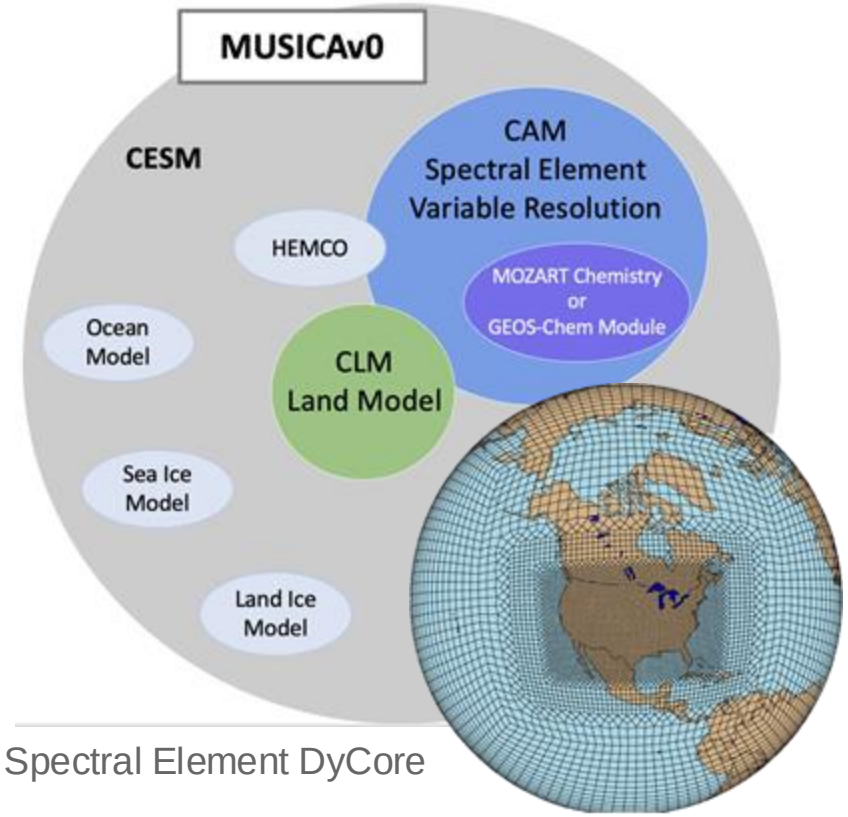
Goal: MUSICA is part of chemical transport models that represent
- urban/local to regional to global scales
- surface up to the top of the atmosphere
- two-way coupling with other Earth system components

to address frontier science questions.

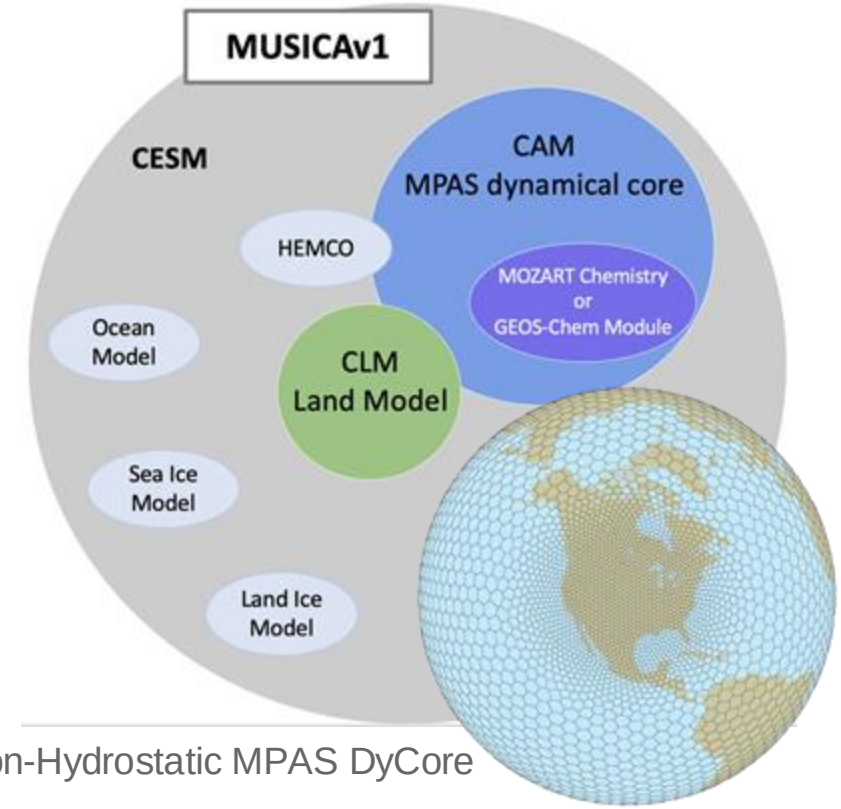
Two-prong approach to MUSICA development

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

MUSICA versions 0 and 1



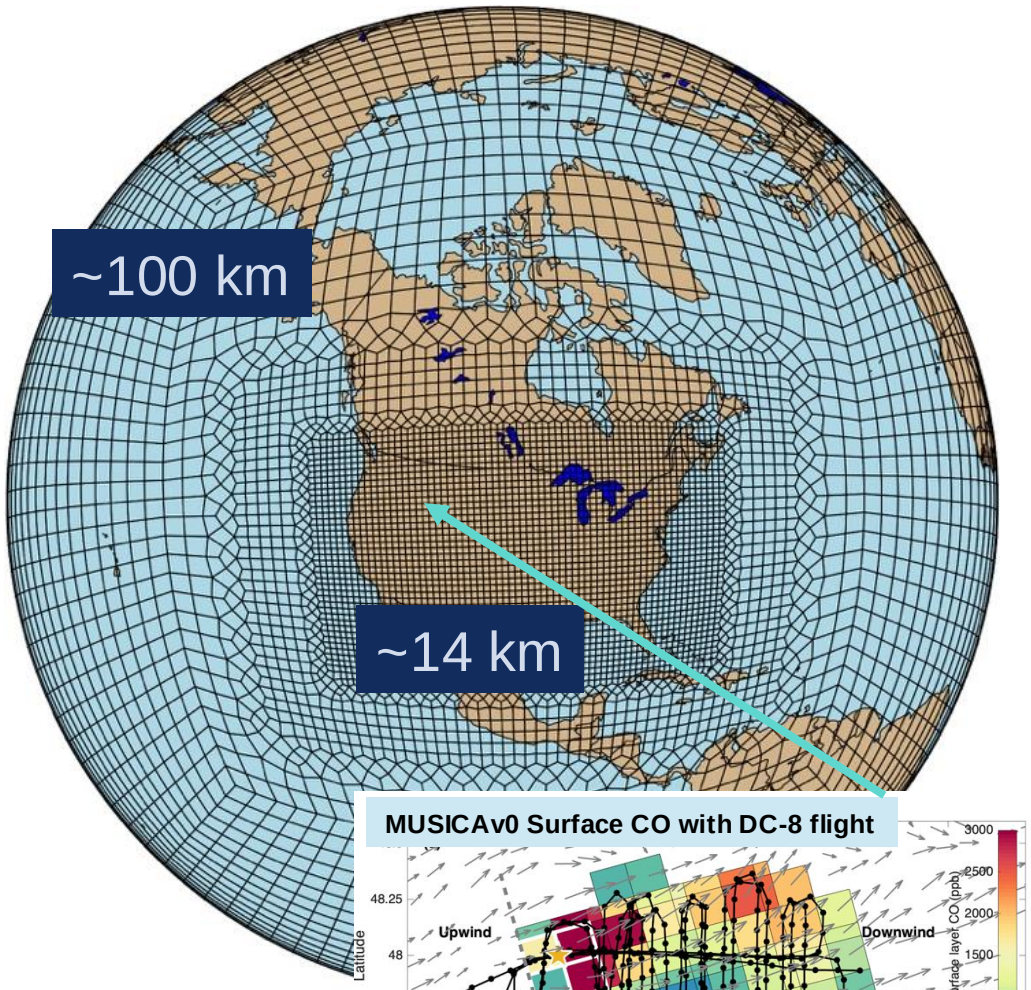
Hydrostatic Spectral Element DyCore

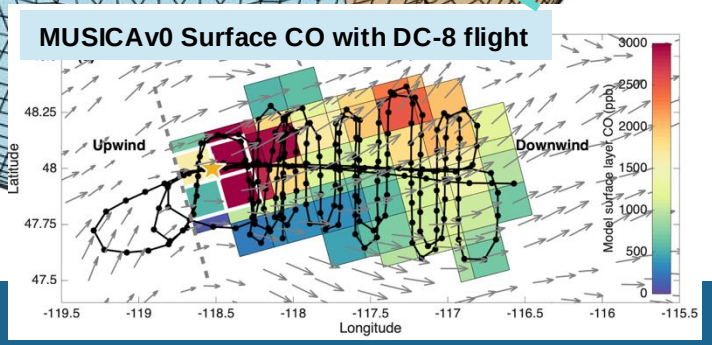


Non-Hydrostatic MPAS DyCore

Configurations of the Community Atmosphere Model (CAM) within the Community Earth System Model (CESM)

MUSICAv0 - released in CESM2.2 – CONUS refined grid





MUSICAv0 is a configuration of the Community Earth System Model (**CESM**):

CAM-chem (Community Atmosphere Model with Chemistry) with Spectral Element (SE) dynamical core and Regional Refinement (RR)

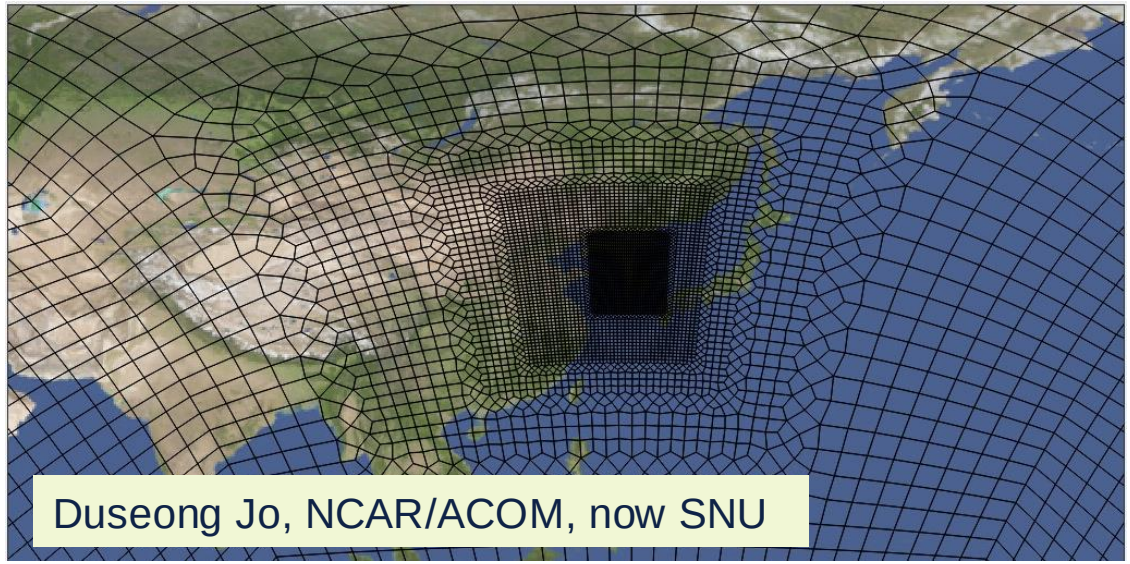
Run nudged to reanalysis meteorology (GEOS/MERRA2) or free-running climate

MUSICAv0 description paper:

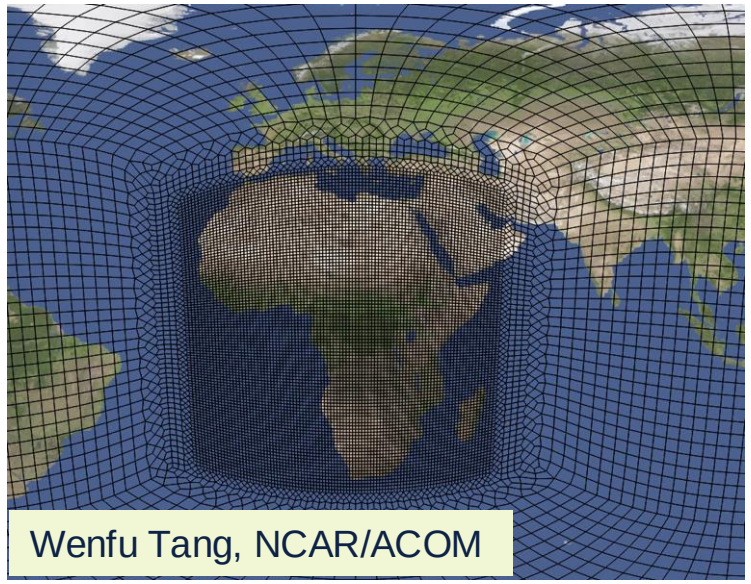
- Chemical complexity vs horizontal resolution [*Schwantes et al., JAMES, 2022*]

Wiki page with instructions to run MUSICAv0:
https://wiki.ucar.edu/display/MUSICA/

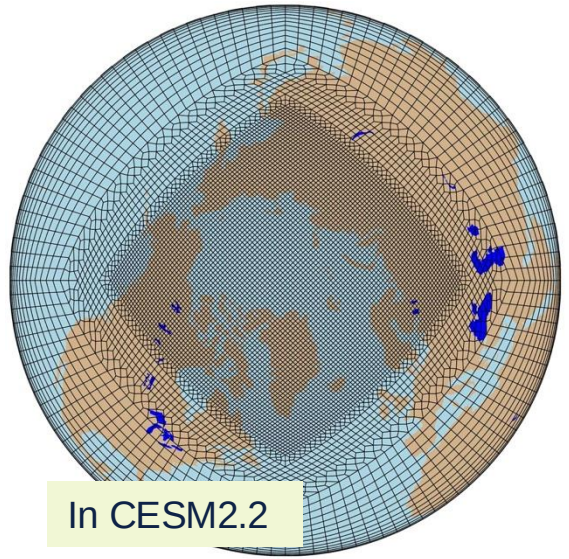
Refined Grids Available for Many Regions



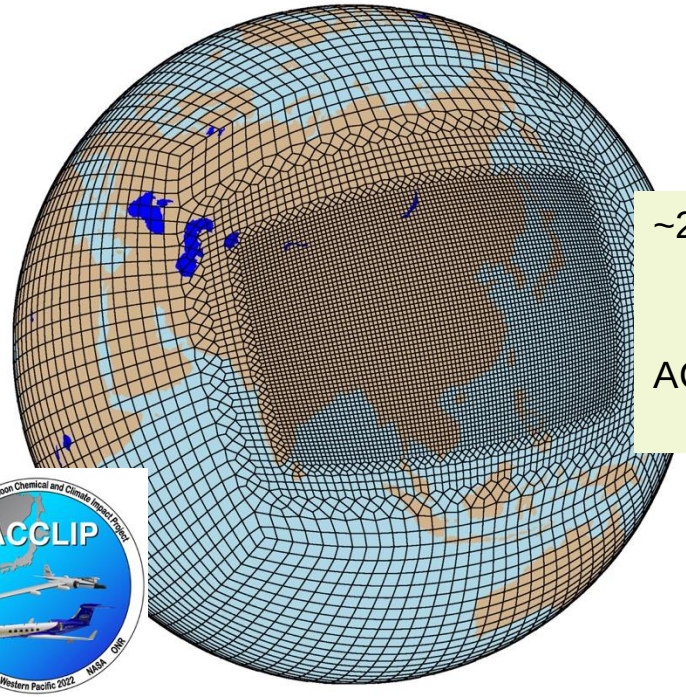
Duseong Jo, NCAR/ACOM, now SNU



Wenfu Tang, NCAR/ACOM

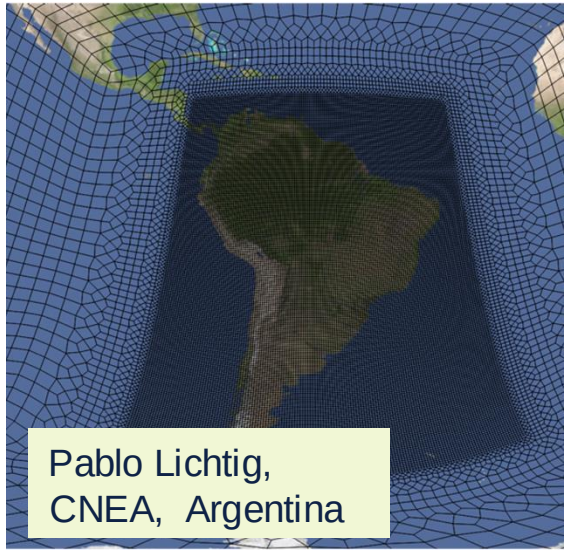


In CESM2.2

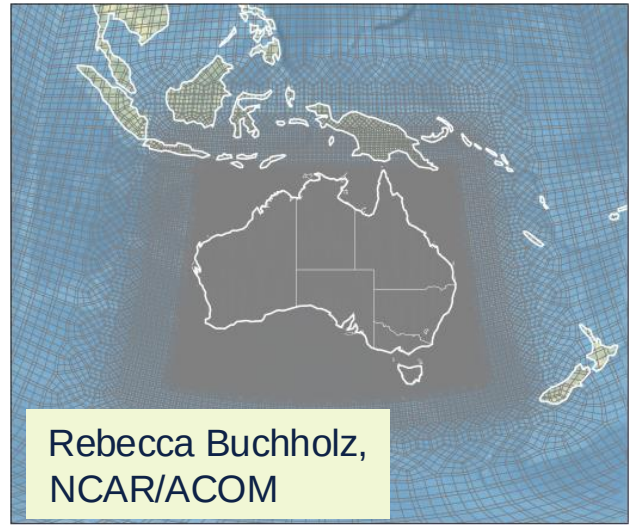


~25 km grid over Asia to study Asian Summer Monsoon and convective outflow

ACCLIP aircraft experiment Aug 2022



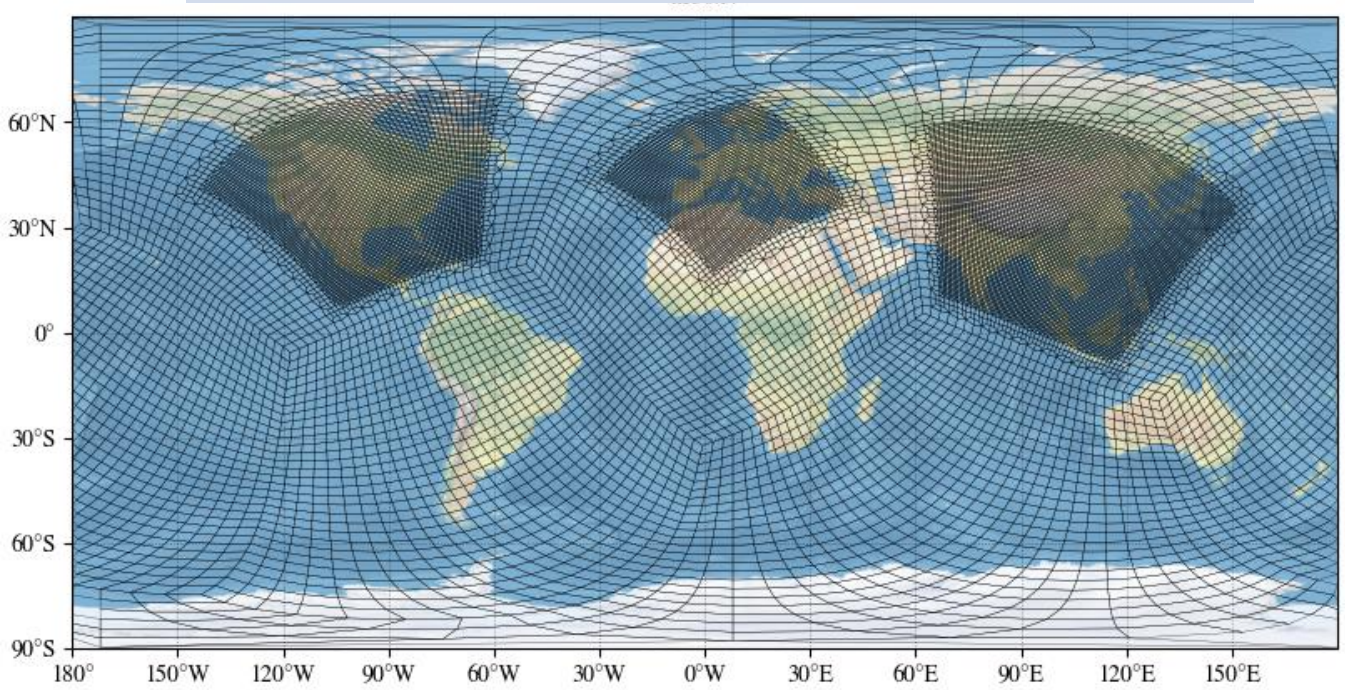
Pablo Lichtig, CNEA, Argentina

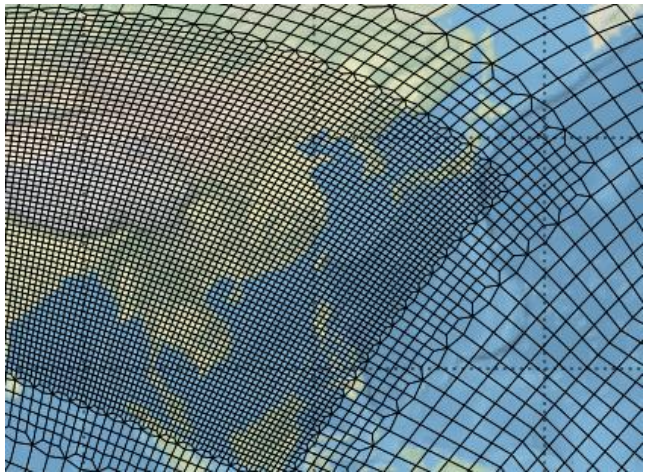


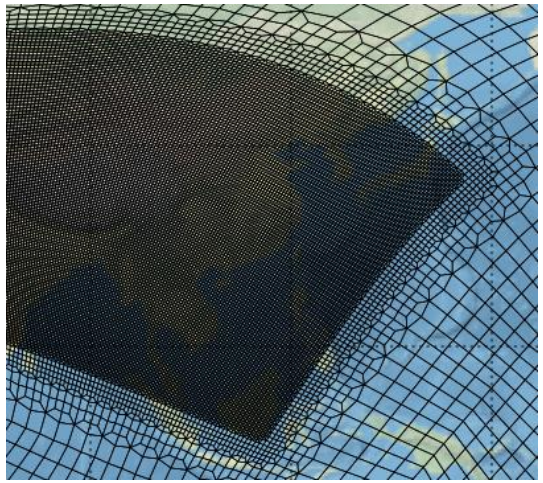
Rebecca Buchholz, NCAR/ACOM

https://wiki.ucar.edu/display/MUSICA/Available+Grids

MUSICAv0 ¼ degree regions in 1 degree global



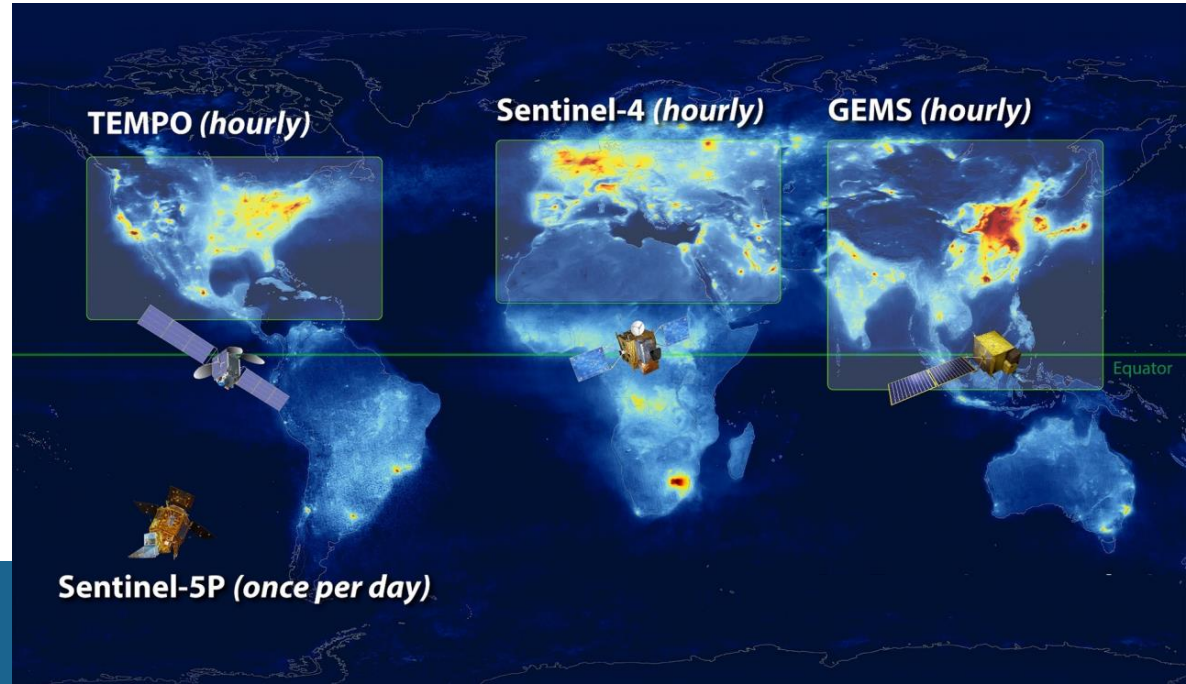




MUSICAv0 regionally refined grid to match the geostationary satellite constellation for atmospheric composition (GEMS, TEMPO, Sentinel-4)

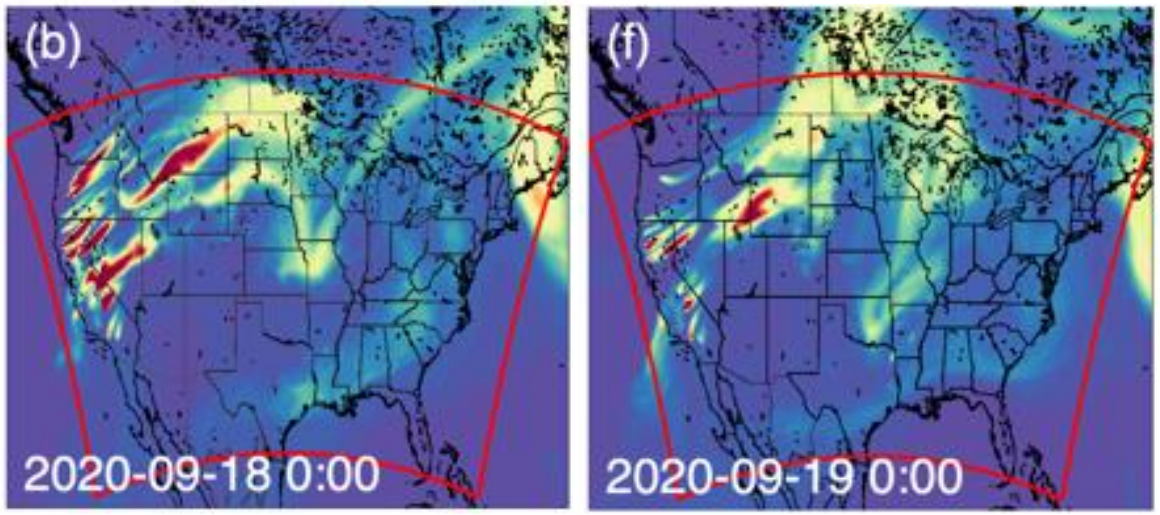
Grids with 25 km or 13 km resolution in each region

Comparing to uniform ~1 degree (100 km) grid



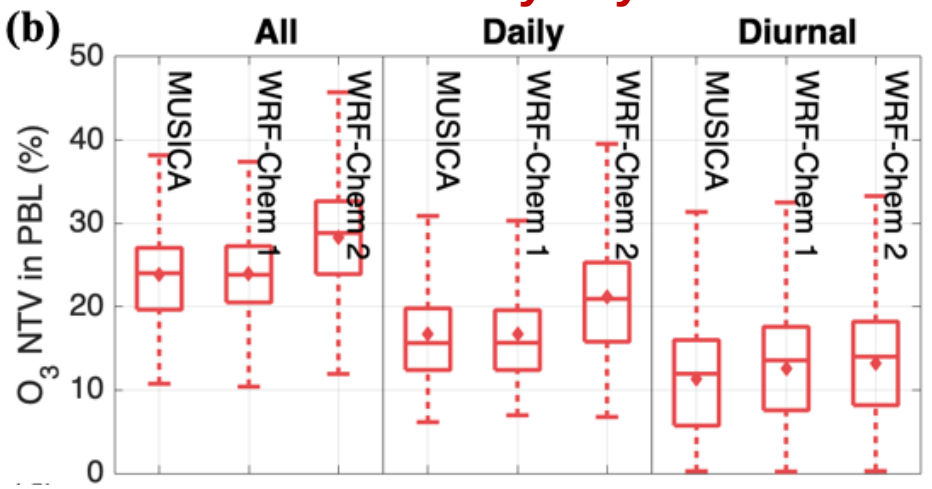
Benefits of MUSICAv0 over regional models

- No inconsistencies due to the use of lateral boundary conditions
- Includes stratospheric chemistry, thus influence of stratospheric ozone on troposphere
- Coupling to all earth system components (land, ocean, ice)



Fire plumes simulated in MUSICAv0 get transported outside of, and back into, the WRF-Chem domain

Ozone Temporal Variability in Boundary Layer



Temporal variability statistics show ranges of ozone and PM2.5 are similar in MUSICAv0 and 2 WRF-Chem configurations, on monthly, daily and hourly scales

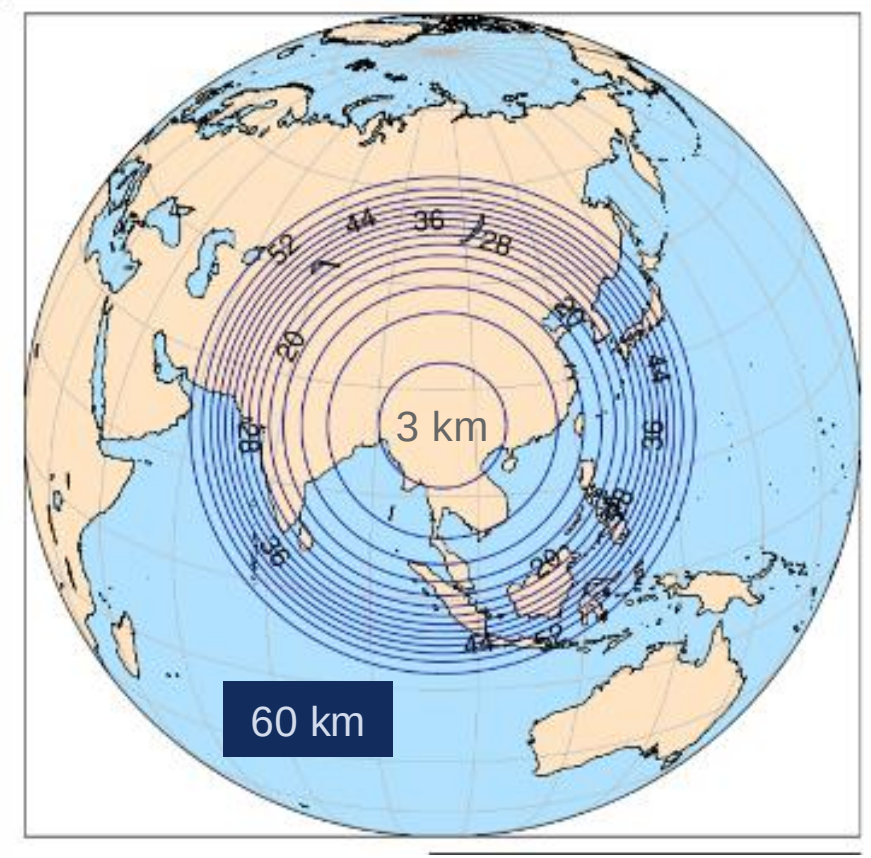
MUSICAv1: Tests of CAM-MPAS with full chemistry

Uniform grid: 60 km resolution (163,842 columns)
Refined grid: 60 km to 3 km grid mesh (835,586 columns)

Testing with full chemistry:

1) Centered over Asian Monsoon (ACCLIP, August 2021):
   Examine impacts of spatial and temporal grid resolution on convective transport of trace gases
   [Mary Barth, Ren Smith]

2) Centered over Manila (ASIA-AQ, Feb 2024):
   Local vs transported pollution
   [Wenfu Tang]

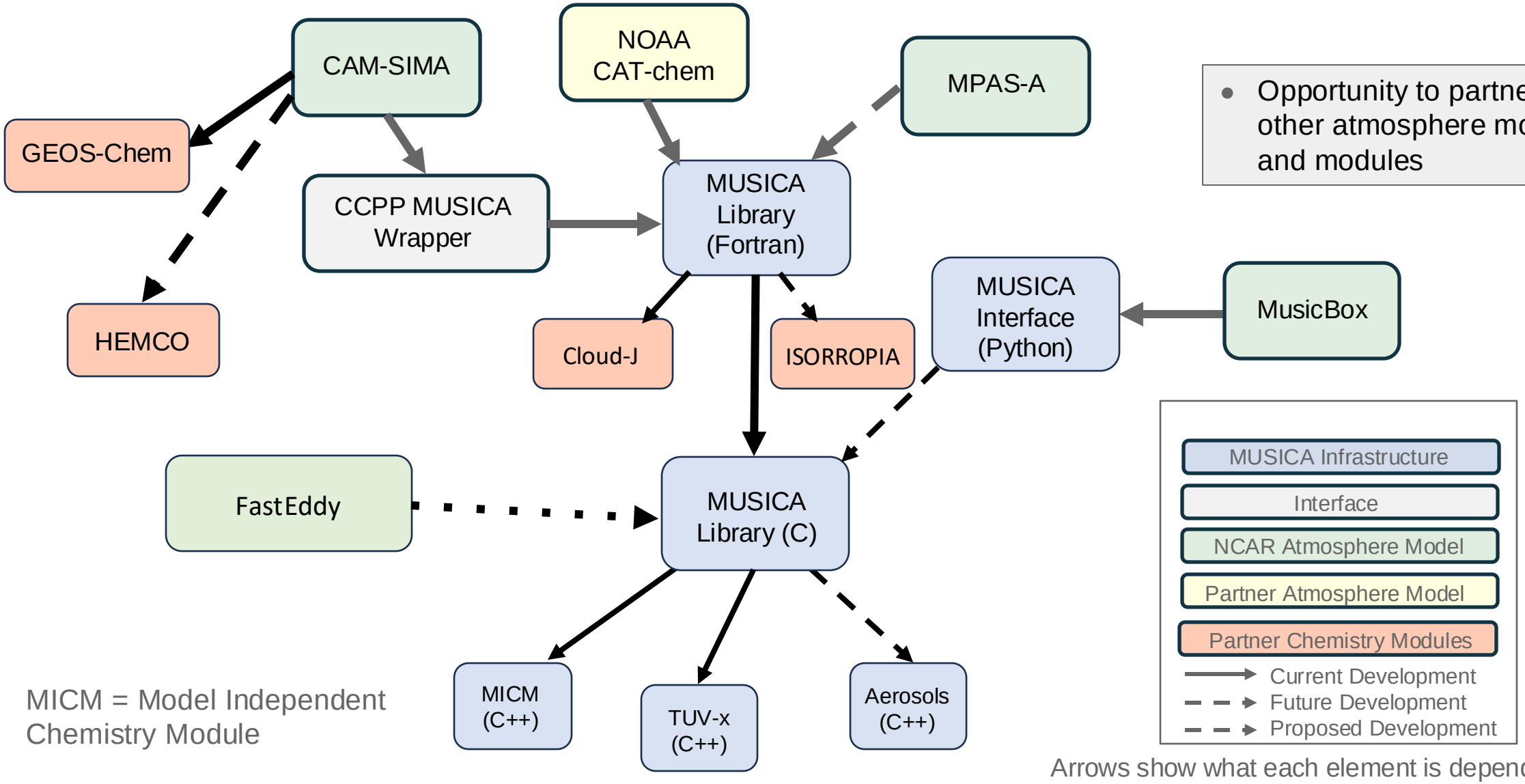


Developing Infrastructure for Model Independent Code

Goals for Designing the Infrastructure

- Science-based configuration
  - Ensure model configurations are based on science needs by practicing **implementation hiding** and top-down test-driven development
- Extensibility to new science
  - Standards for **unit testing** ensure new code works as expected and existing code does not break with new feature additions
  - Science components that build as **stand-alone software libraries** with well-defined APIs provide modularity
- Improved user experience
  - **Run-time configuration** permits configuration without modifying code or rebuilding software

MUSICA Software Development Ecosystem



- Opportunity to partner with other atmosphere models and modules

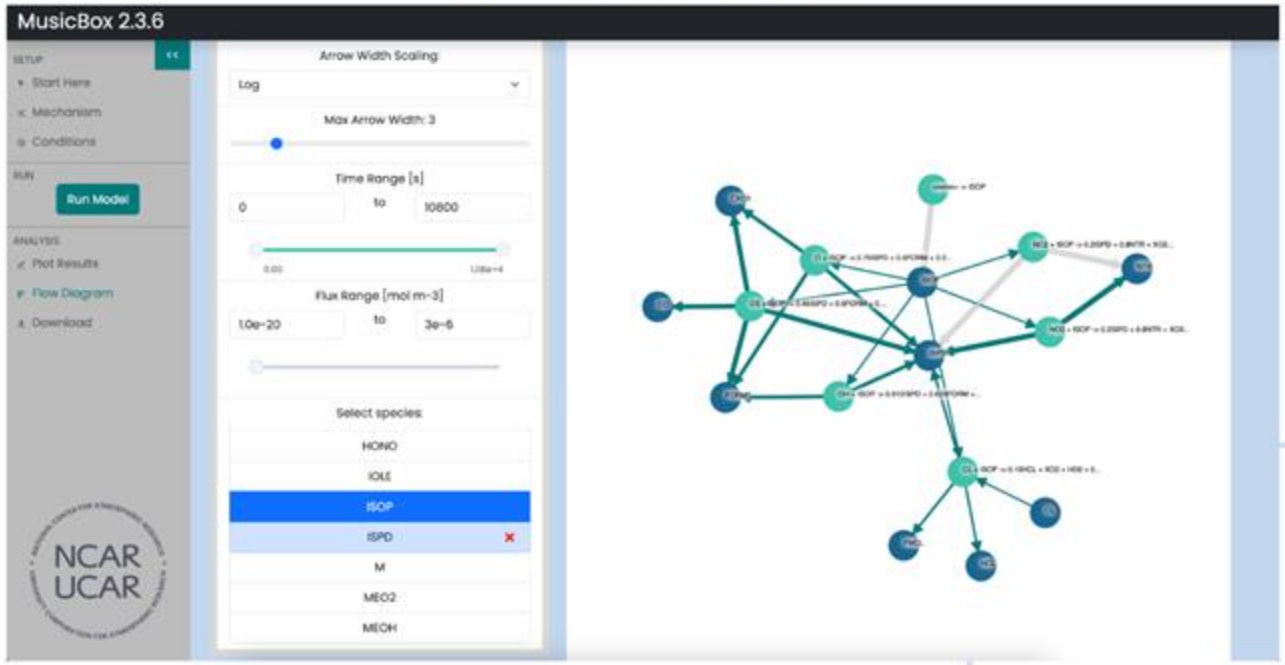
MICM = Model Independent Chemistry Module

Arrows show what each element is dependent upon

MusicBox Interactive Chemistry Model

MusicBox: Interactive box model

http://musicbox.acom.ucar.edu



- Test code development
- Enable scientific research
- Use for classroom/training

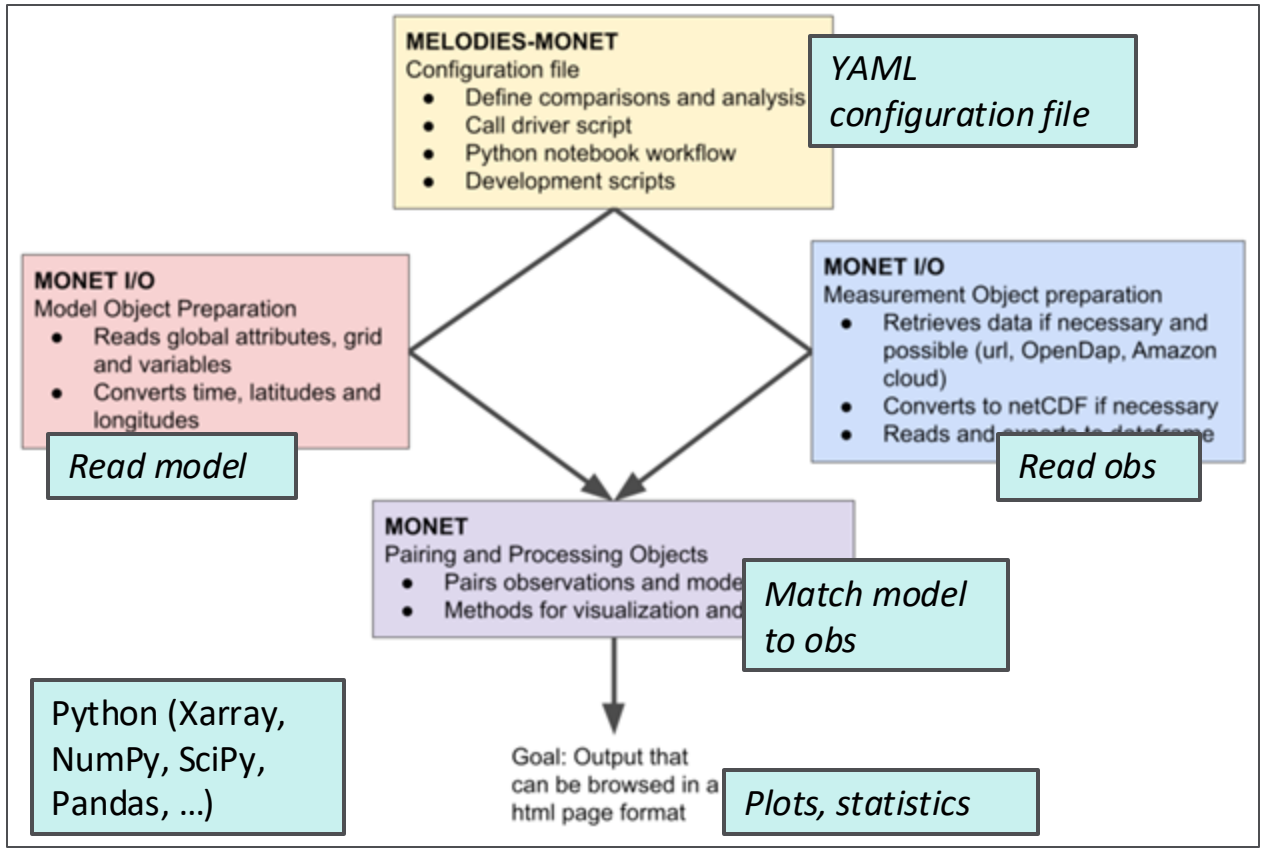
Flow diagram of chemical pathways with arrows proportional to reaction rates from MusicBox

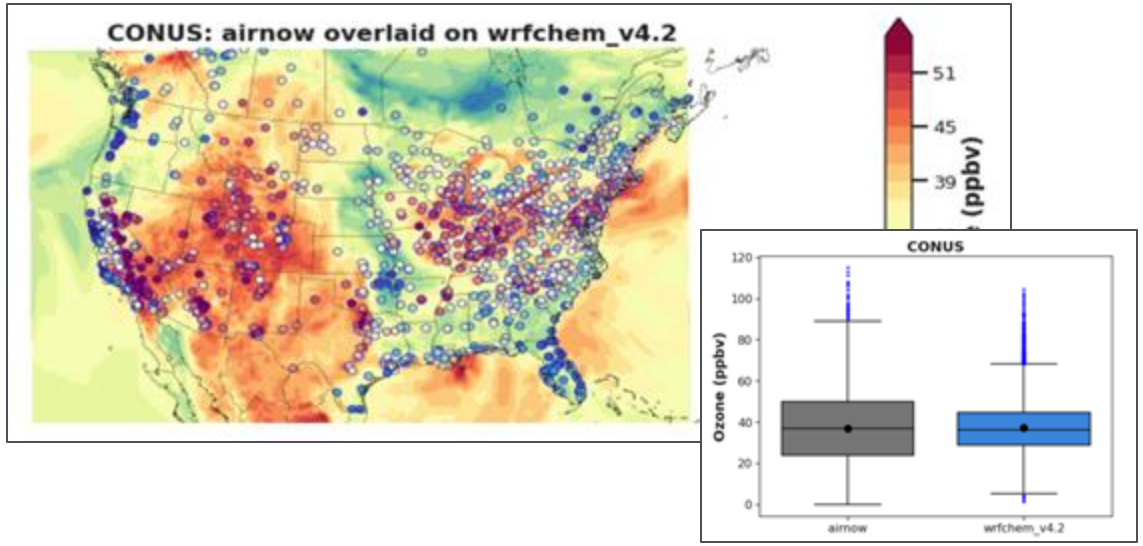
MusicBox

A modular framework to compare model results and observations of atmospheric chemistry

MELODIES: Model EvaLuation using Observations, DIagnostics and Experiments Software

MONET: Model and ObservatioN Evaluation Toolkit





https://github.com/NOAA-CSL/MELODIES-MONET

NCAR MELODIES PI: Louisa Emmons

NOAA: Becky Schwantes, Barry Baker and others

Ave Arellano - U. Arizona; Gao Chen - NASA Langley

& the community

Summary

MUSICA

- Is being **developed collaboratively** with university and government researchers
- Is the next-generation community infrastructure at NCAR **for atmospheric chemistry & aerosol research**
- To contribute to both **advancing the science** and to providing **relevant and actionable information** for the development of mitigation policies or warning systems

Frontier Science Applications

- Local air quality (AQ) forecasts in global context
- Seasonal and sub-seasonal AQ predictability
- Impact of intercontinental transport and chemistry on local AQ and vice versa
- Impact of whole atmosphere on tropospheric chemistry predictability
- Predictions of future, regional air quality under a changing climate
- and many more …

Opportunities for Collaboration

MUSICA
Multiscale Infrastructure for Chemistry and Aerosols

- Join MUSICA Working Groups: Model Architecture, Emissions & Deposition, Chemical Schemes, Aerosols, Physics & Transport & sub-scale Processes, Whole Atmosphere, Evaluation & Data Assimilation
- Sign up for MUSICA Newsletter and read past issues: https://www2.acom.ucar.edu/sections/multi-scale-chemistry-modeling-musica (QR code)
- CESM Annual Workshop (June) and Winter Working Group meetings (Feb or March)
- CESM and MUSICA GitHub sites:
  CAM: https://github.com/ESCOMP/CAM (includes CAM-chem and WACCM)
  MUSICA: https://github.com/NCAR/musica
- NCAR Visitor Programs and fellowships:
  Advanced Study Program (ASP), grad students and postdocs:
  https://edec.ucar.edu/advanced-study-program
  ACOM visitors: https://www2.acom.ucar.edu/opportunities/acom-visitor-program

MUSICA website:

emmons@ucar.edu

Thank you!

谢谢