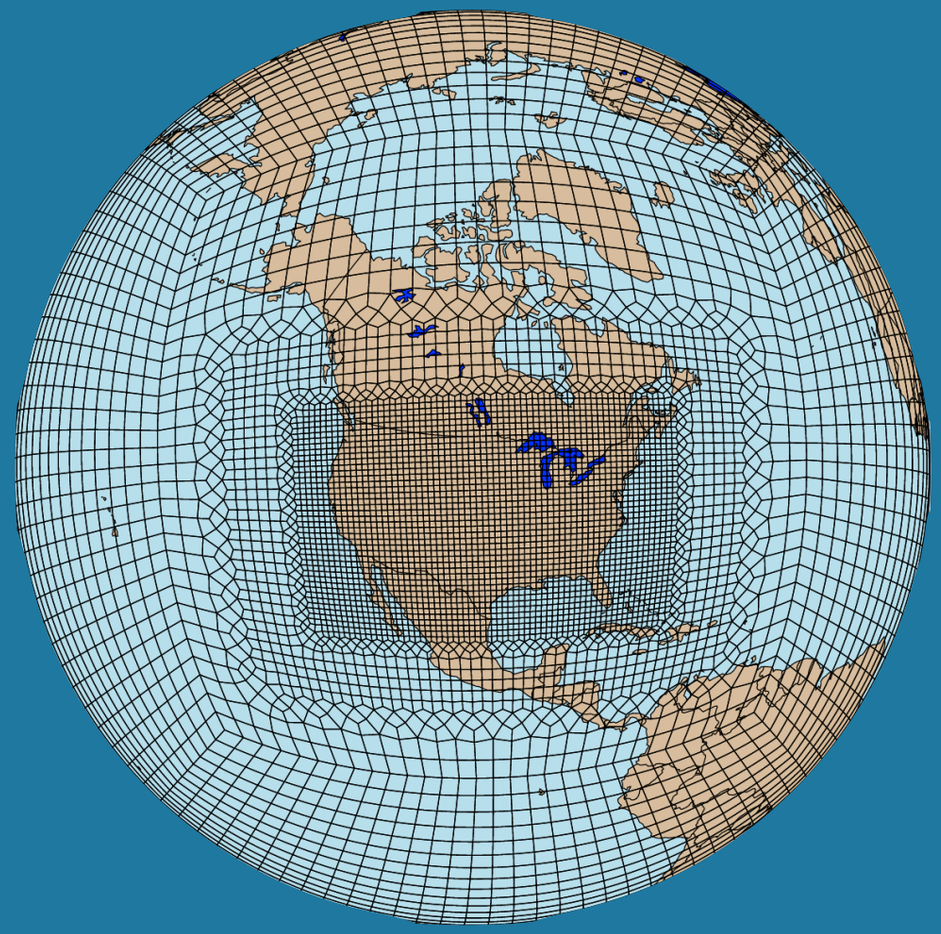
Whole Atmosphere Modeling and Science in MUSICA

Nicholas Davis

With special thanks to Andrew Conley, Peter Lauritzen, Simone Tilmes, Louisa Emmons, Forrest Lacey, and Becky Schwantes



MUSICA
Multiscale Infrastructure for Chemistry and Aerosols

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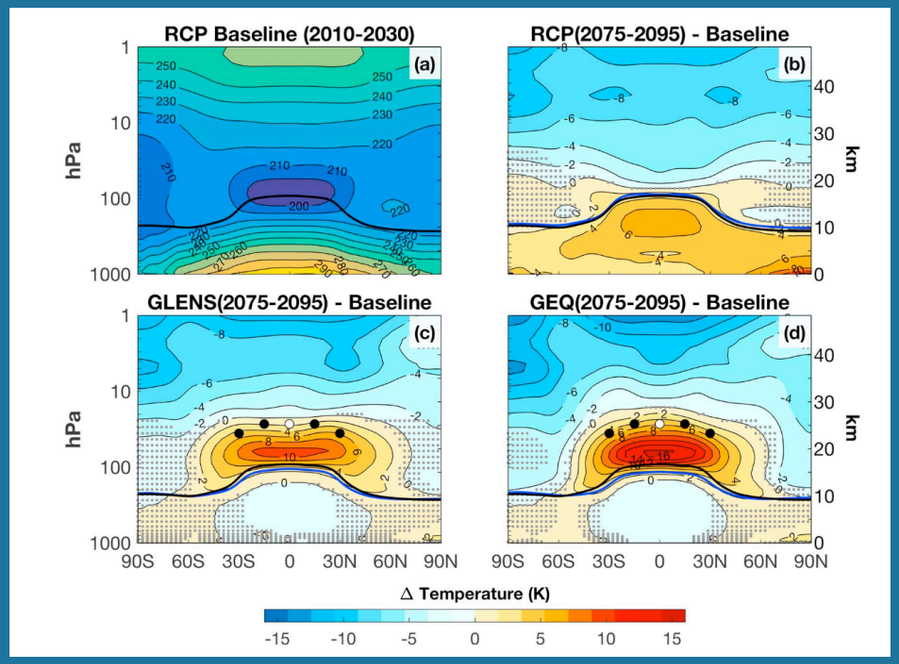
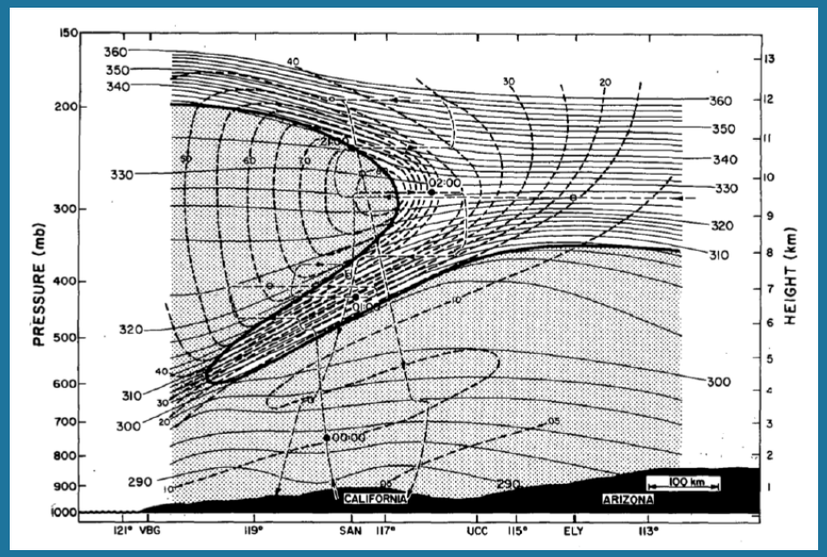
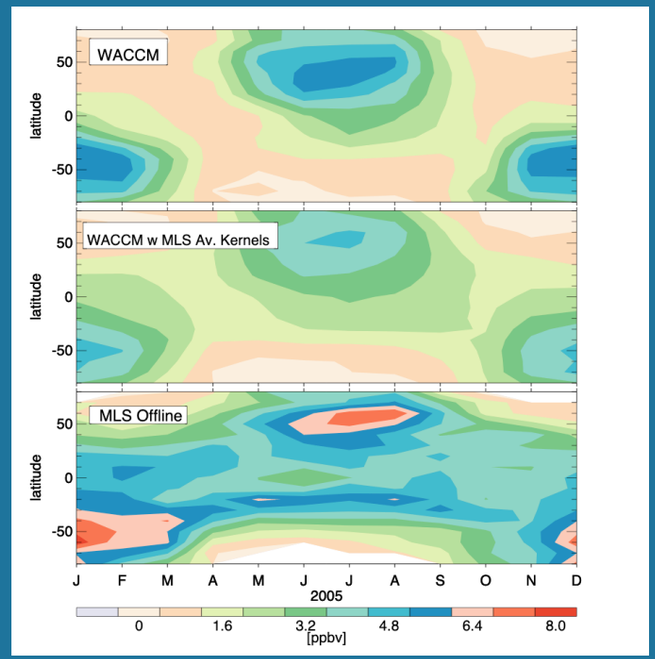
Current challenges in whole atmosphere science



From Kravitz et al. (2019)



From Shapiro (1980)



From Millán et al. (2015)

- **Stratosphere-troposphere exchange**
  - *Ground-level ozone and climate change*
- **Stratosphere-troposphere coupling**
  - *How does stratospheric variability project onto the surface?*
- **Gravity wave transport in the mesosphere-lower thermosphere**
  - *Evidence that WACCM underestimates transport - by how much?*
- **Asian summer monsoon**
  - *How does pollution and water vapor enter the stratosphere?*
- **Geoengineering**
  - *Uncertainty and efficacy*
- **Brewer-Dobson circulation change**
  - *Fundamental wave-mean flow physics*

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Current challenges in whole atmosphere science

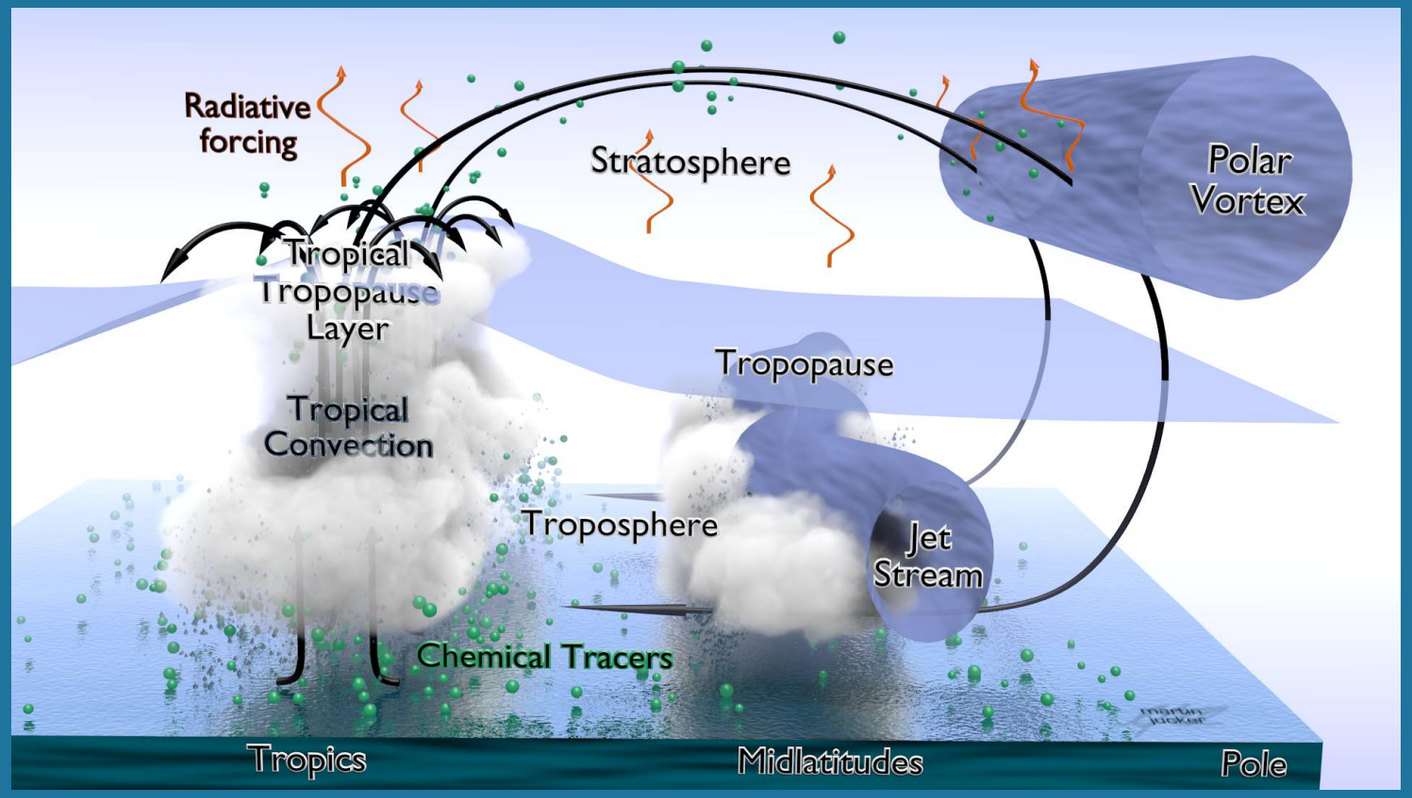
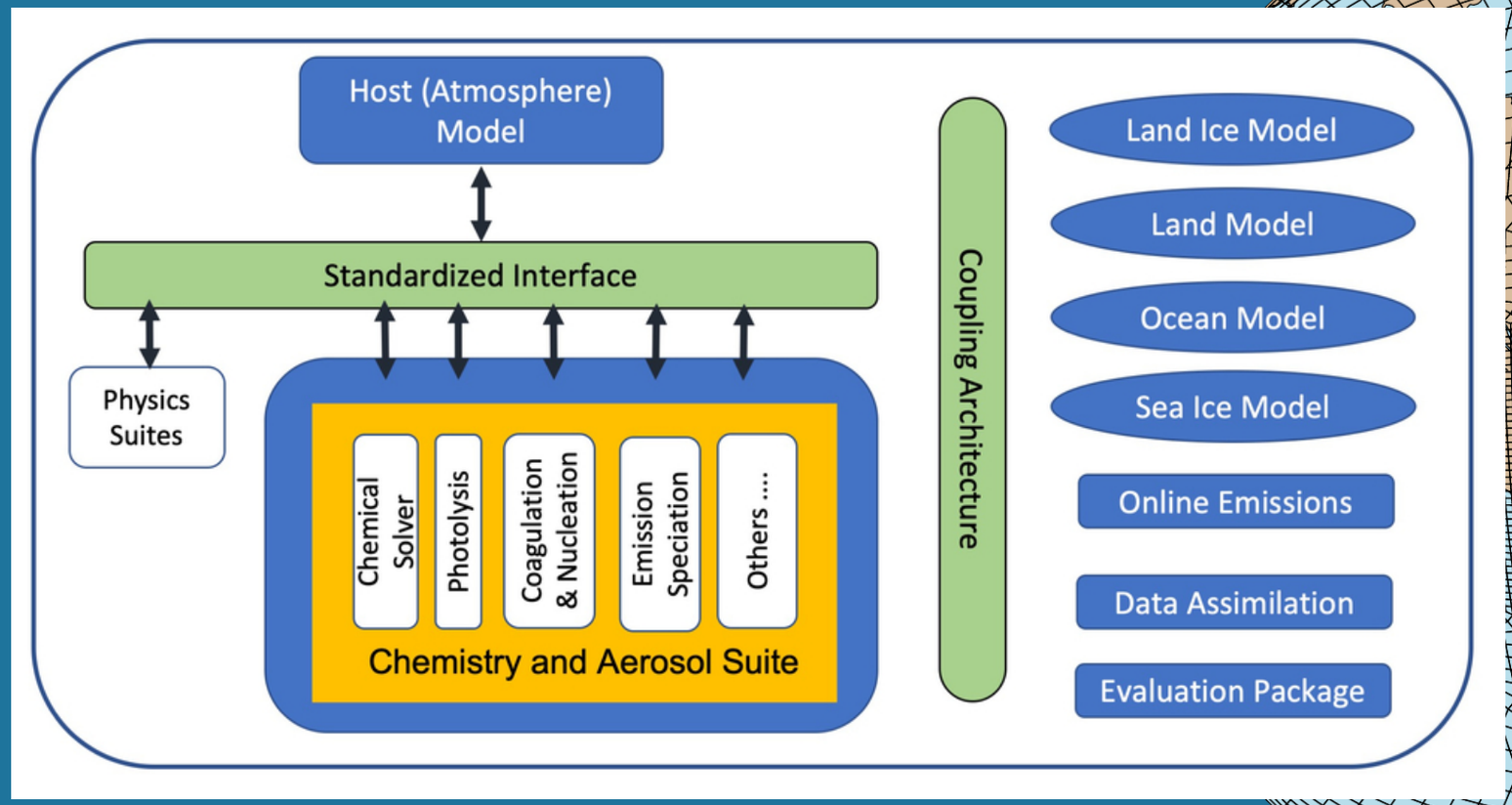


Image from Martin Jucker

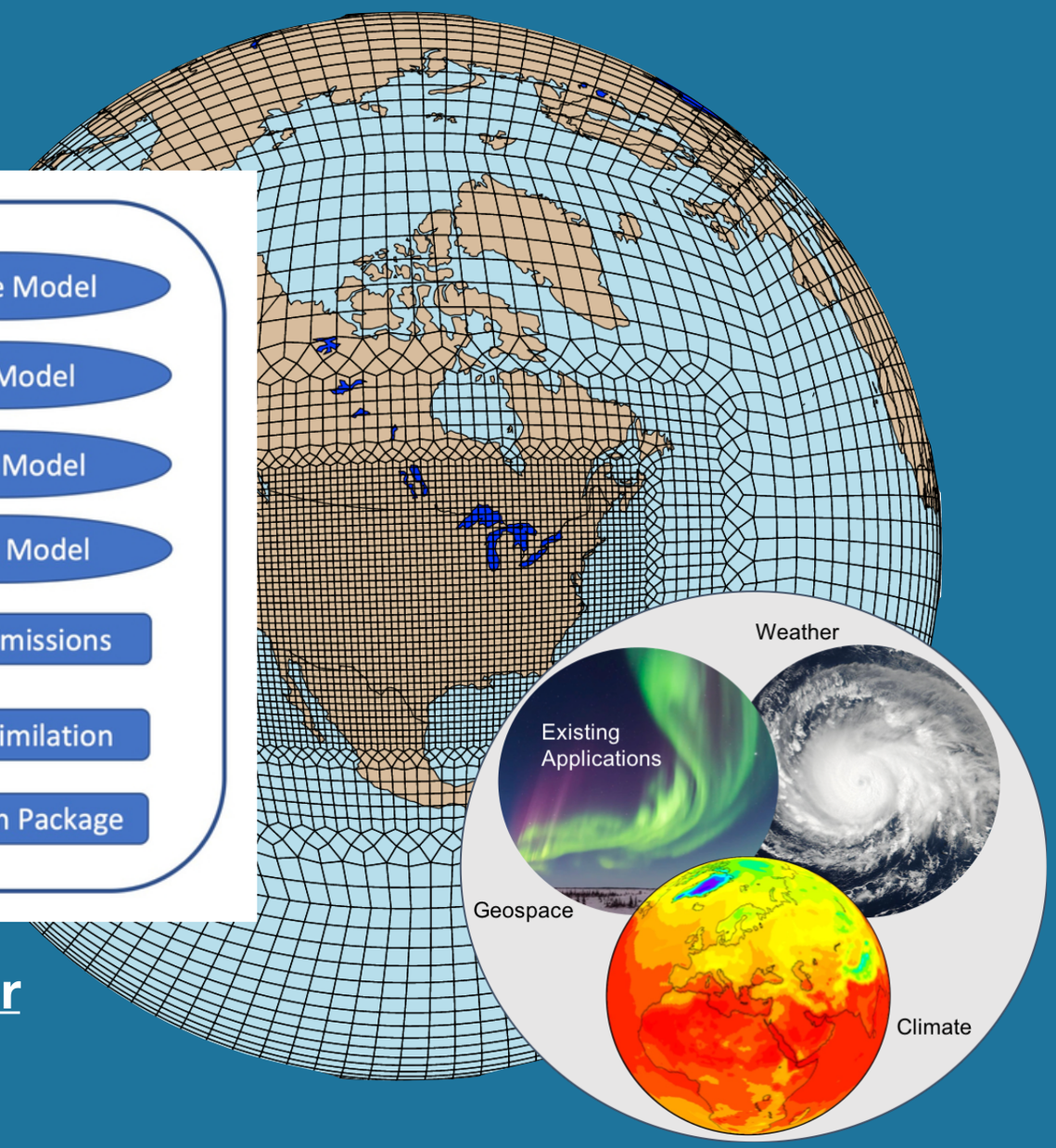
These are vertical coupling problems that require higher horizontal *and* vertical resolution, *and* creative new modeling techniques

- Stratosphere-troposphere exchange
- Stratosphere-troposphere coupling
- Gravity wave transport in the mesosphere-lower thermosphere
- Asian summer monsoon
- Geoengineering
- Brewer-Dobson circulation change

What is MUSICA?



MUSICA (Multi-Scale Infrastructure for Chemistry and Aerosols): coupled chemistry modeling in SIMA



SIMA (System for Integrated Modeling of the Atmosphere): unified modeling system that can address weather, climate, and geospace applications

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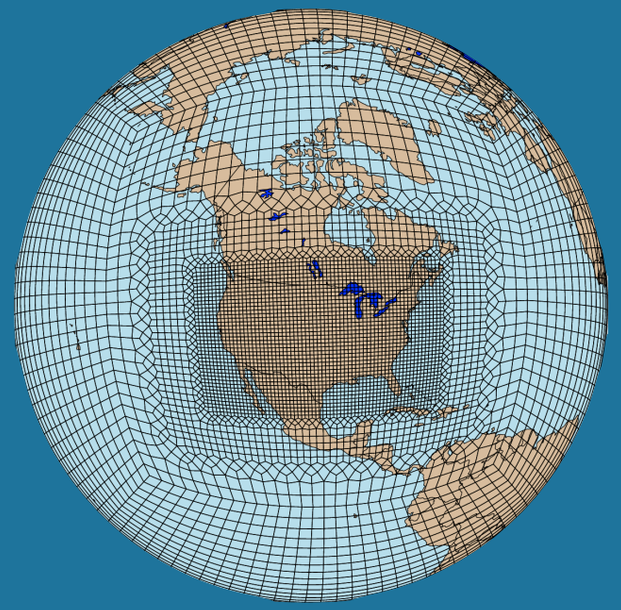
The future of whole atmosphere science in MUSICA

Key MUSICA features

- Modular framework to swap physics parameterizations and components
- Refined-mesh support in spectral element (SE) dynamical core

What does this mean in practice?

- Resolve smaller horizontal scales: gravity waves, chemical transport in key geographic regions
- Rapidly iterate chemical and aerosol schemes to test sensitivities, mechanisms, and uncertainties
- Integrate “science” packages into MUSICA/SIMA to support better community-wide research



What challenges does this present?

- The “gray zone” of gravity wave dynamics
- Zonal-mean output package to handle arbitrary meshes
- Transition existing WACCM physics to SIMA

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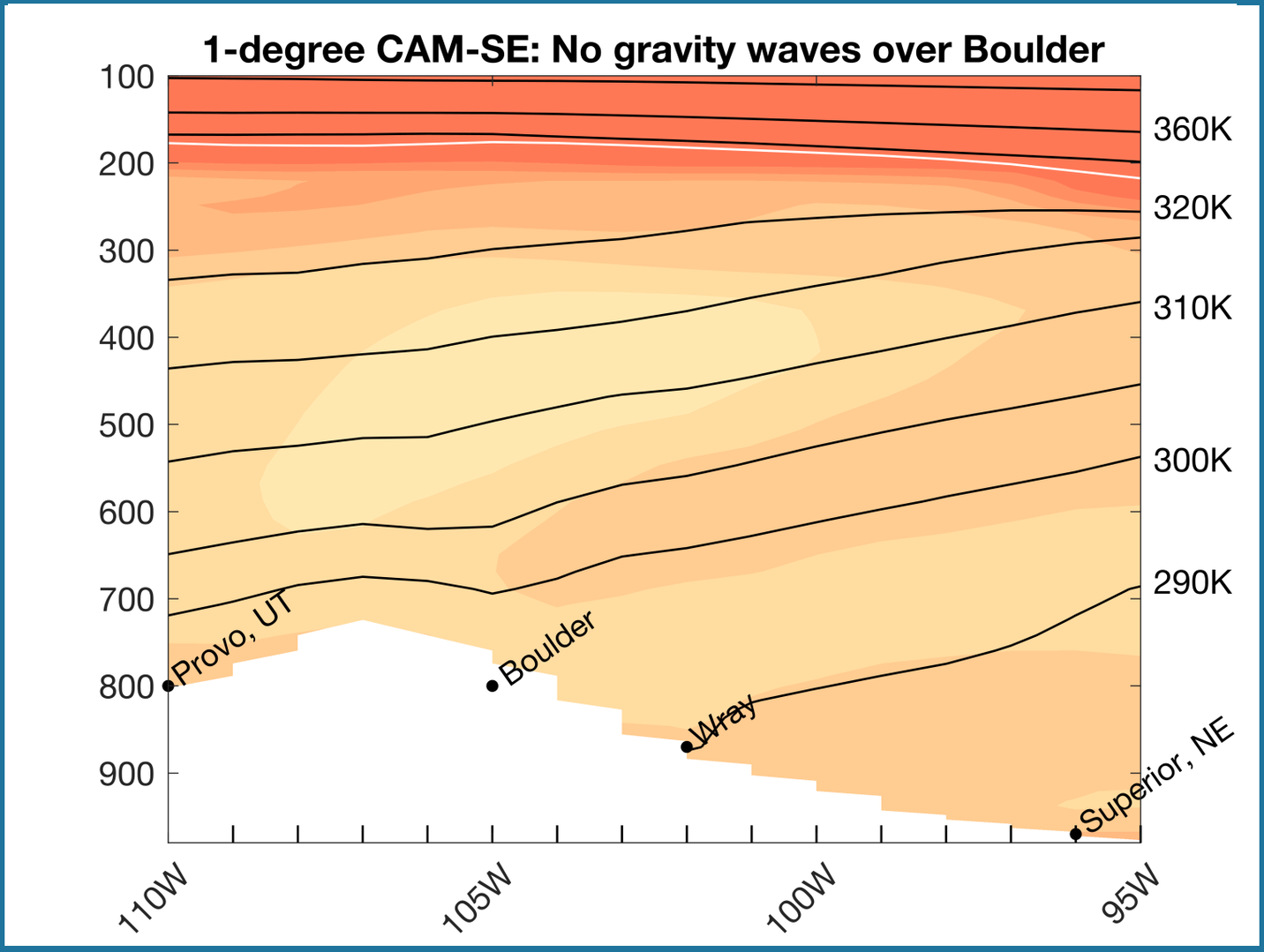
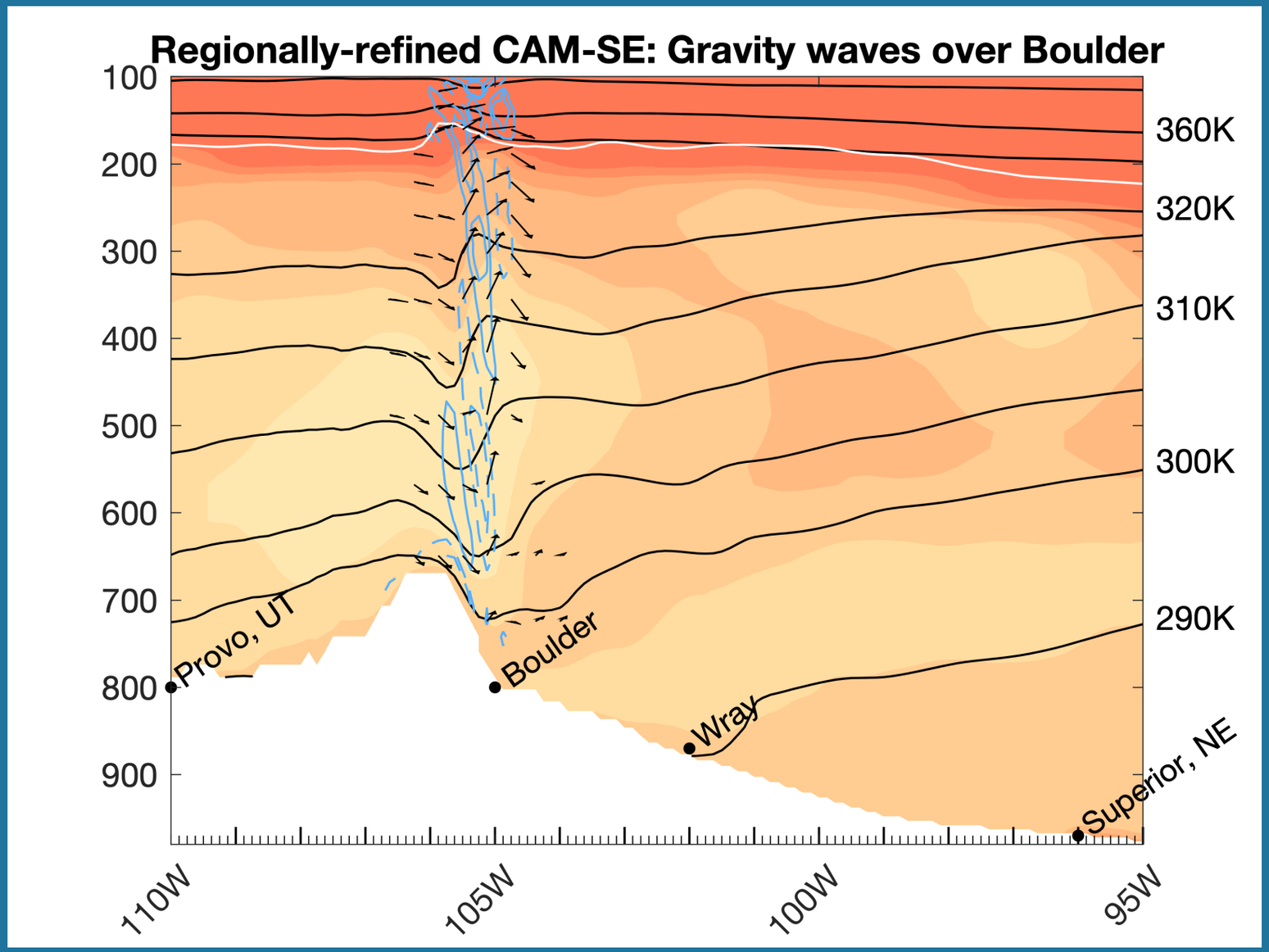
Regionally-refined CAM-SE: the gravity wave grey zone

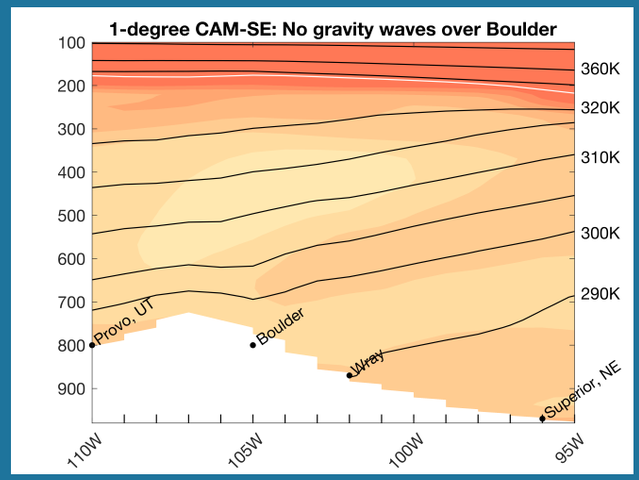


Output from CAM-Chem-SE and CAM-Chem-SE-RR, 1 degree global and 1/8 degree refined resolution.

Regionally-refined CAM-SE: the gravity wave grey zone



Blue contours: vertical momentum flux convergence, every 100 m/s/day
Shading: fraction of ozone that is stratospheric in origin
Vectors: vertical and zonal wind
White contour: tropopause

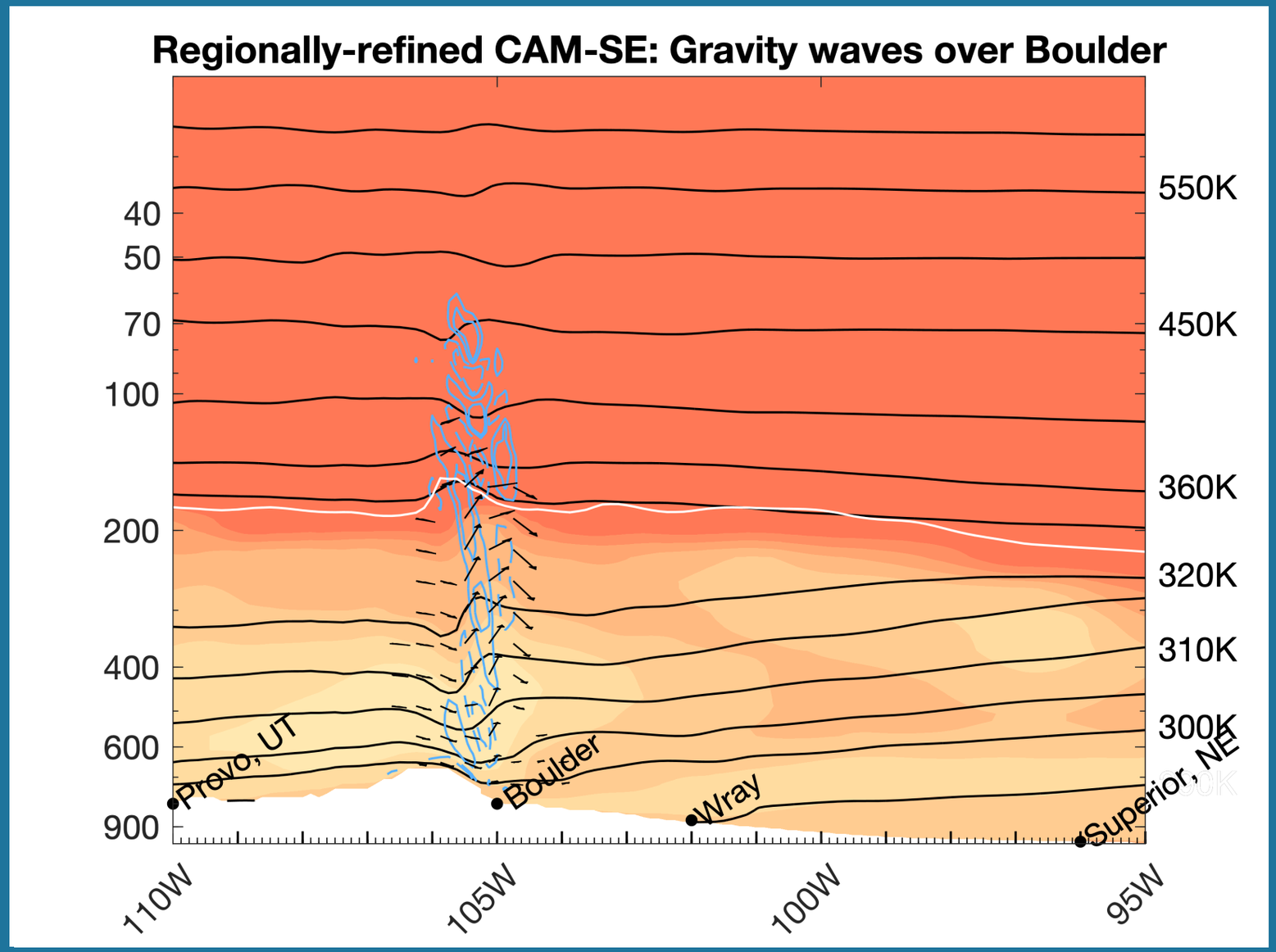


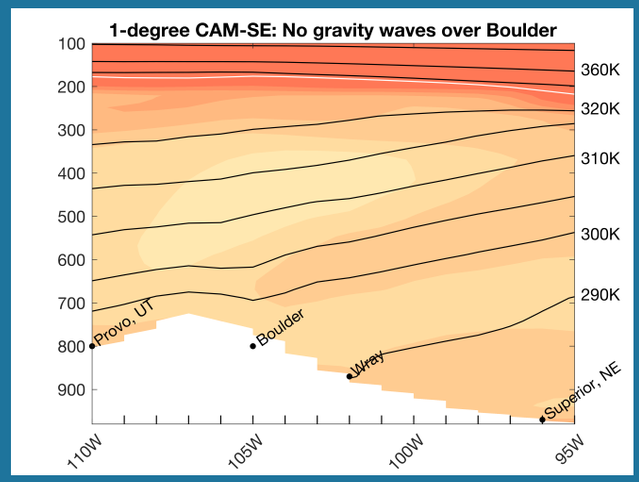
Resolved gravity wave with <100 km wavelength

Momentum forcings in excess of 200 m/s/day

Upward propagation through the stratosphere

Regionally-refined CAM-SE: the gravity wave grey zone





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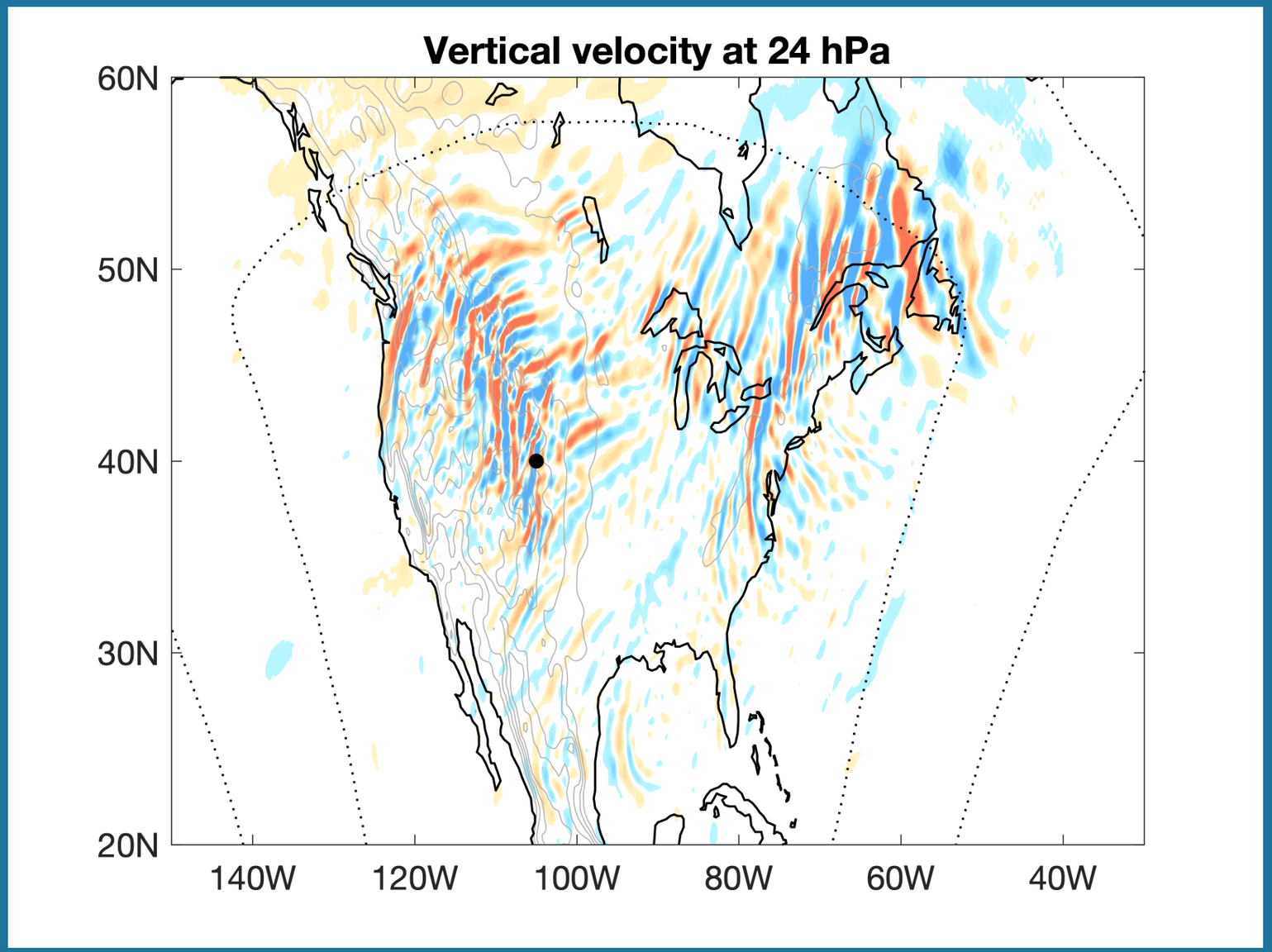
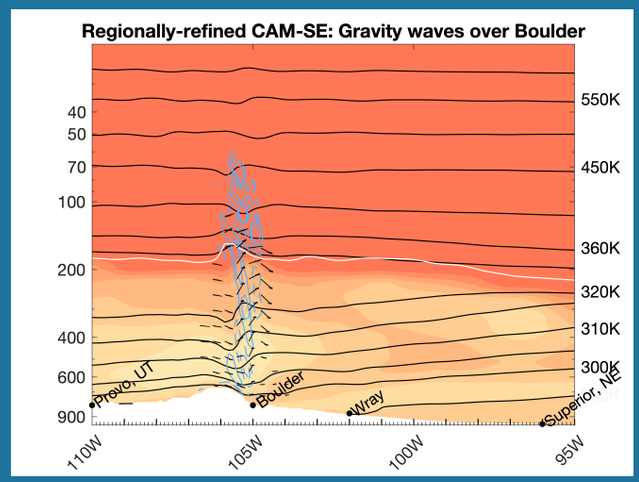
Toward a scale-aware gravity wave scheme



Shading: vertical velocity
Light contours: topographic relief



Both orographic and frontal gravity wave trains in the stratosphere

Frontal waves dissipate at edge of refined mesh

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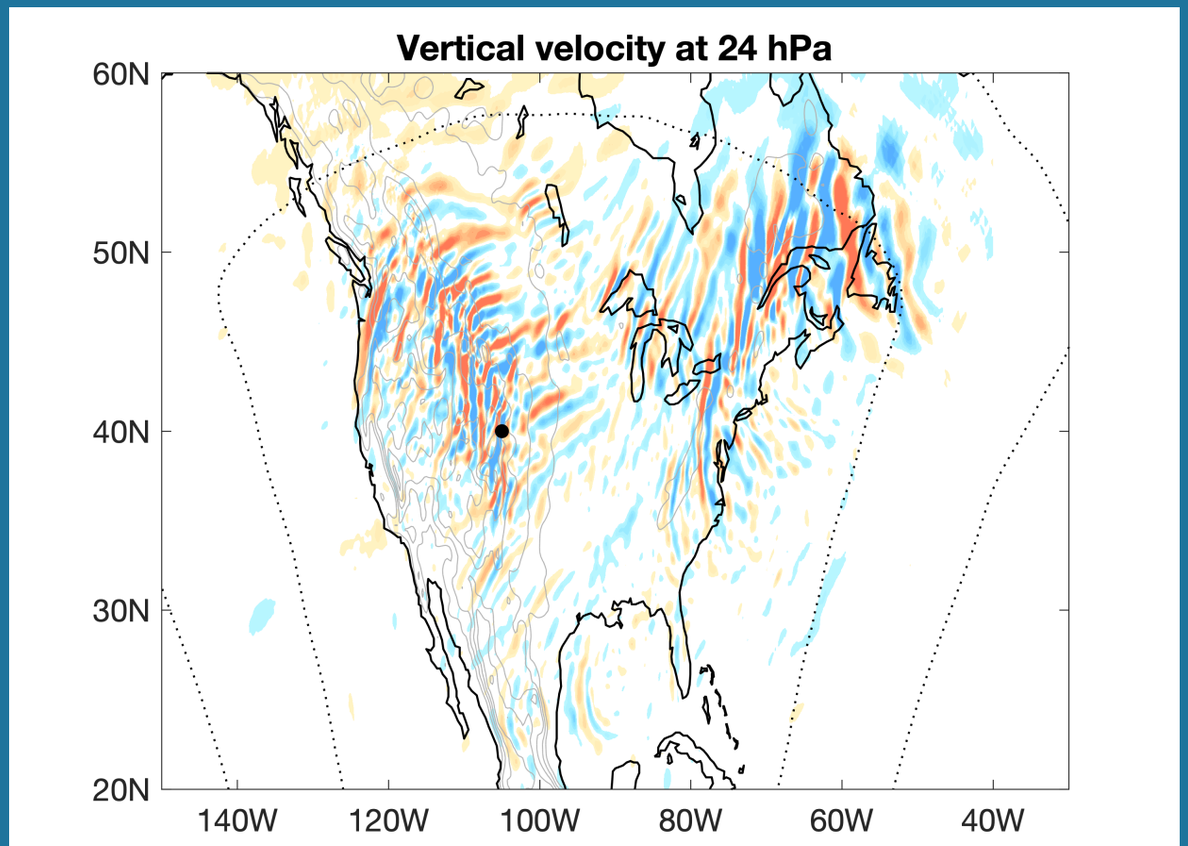
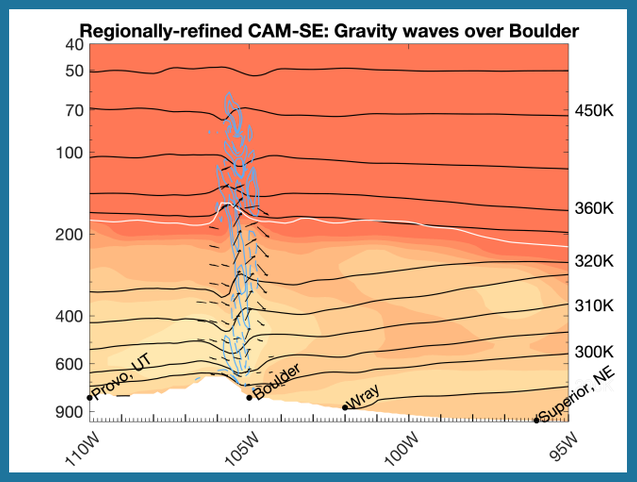
Opportunities for research impacted by gravity waves





Gravity wave parameterizations

- Are the parameterizations doing what the resolved waves do (internal consistency)?

QBO

- Tropical mesh to resolve convective gravity waves

MLT transport, future circulation change

- Multiple small meshes over key regions

Observations

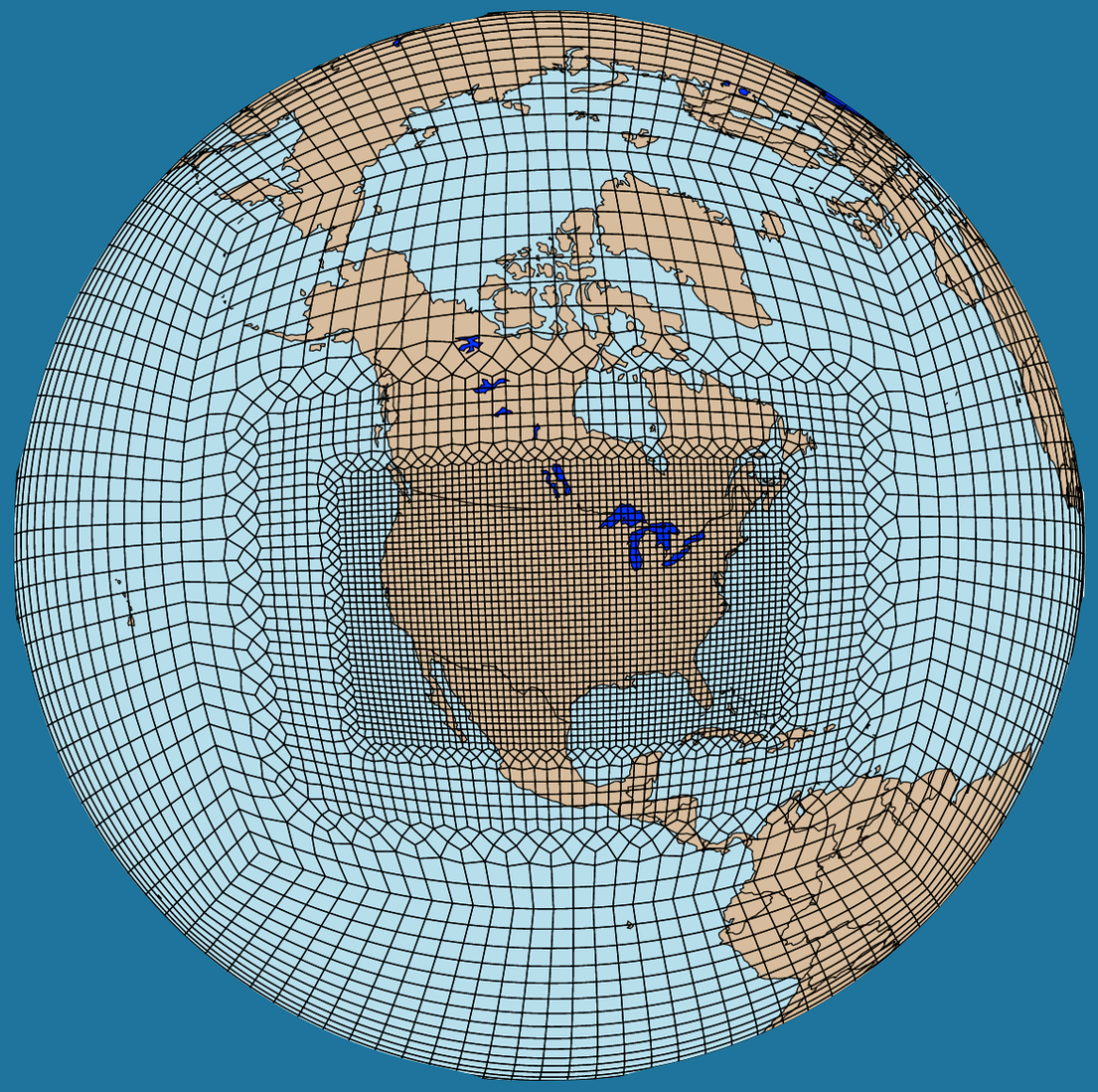
- Field campaign/observing platform support - drop a refined mesh on your region of interest

Extended opportunities

Subseasonal-to-seasonal prediction
- Mesh over ENSO, forecast regions

Stratosphere-troposphere exchange
- Better resolution of stratospheric injections in tropopause folds

Asian summer monsoon
- Improved resolution of anticyclone outflow and resulting transport



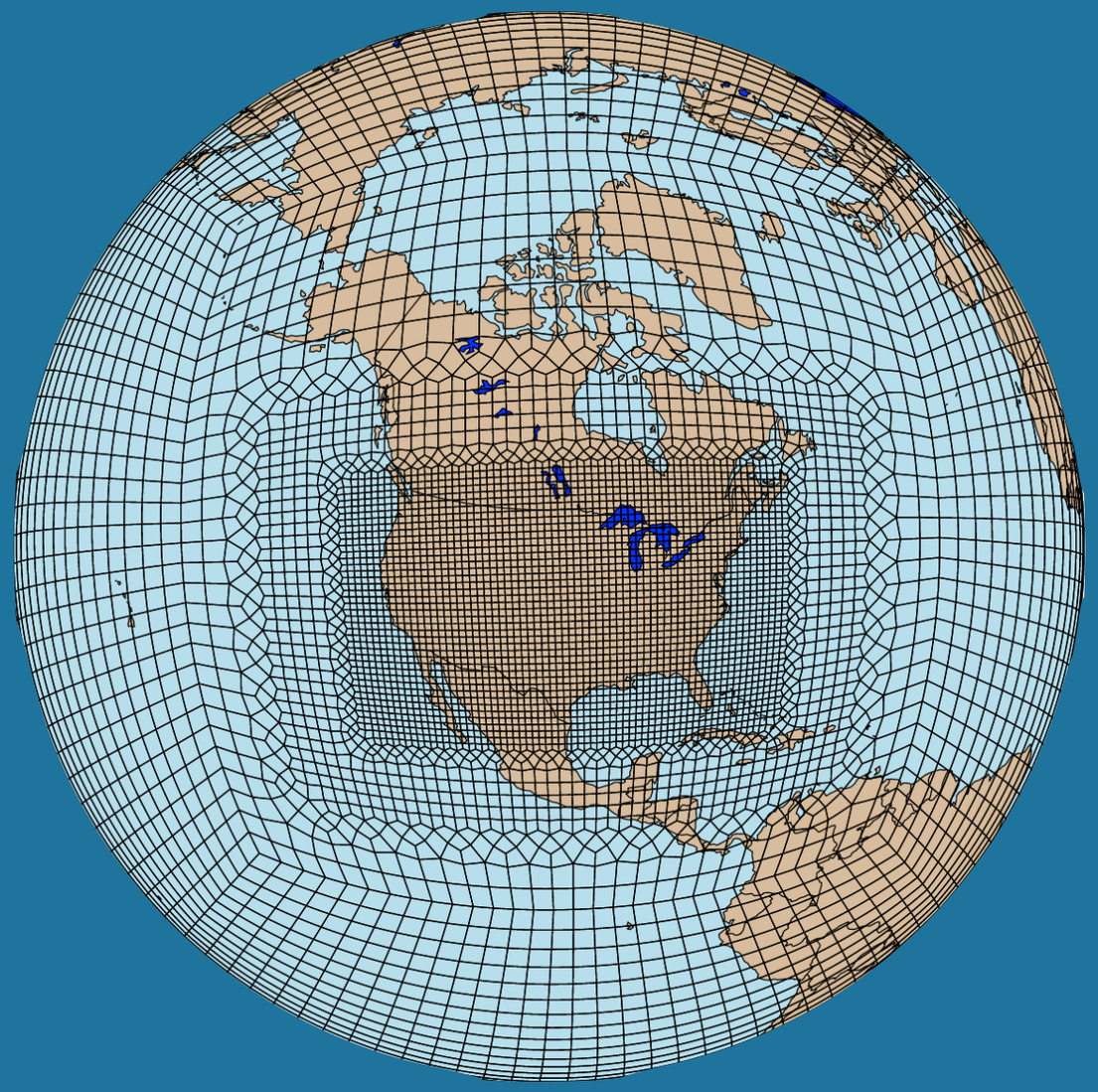
Zonal mean output on arbitrary meshes

Challenges

- What is the zonal mean on an arbitrary non-lat/lon mesh?
- Want internal capability, not just output
- Conventional gridding techniques may be too costly to perform every time step

Solution

- Currently developing a low-order Legendre functional expansion that can operate as a one-way accumulation process



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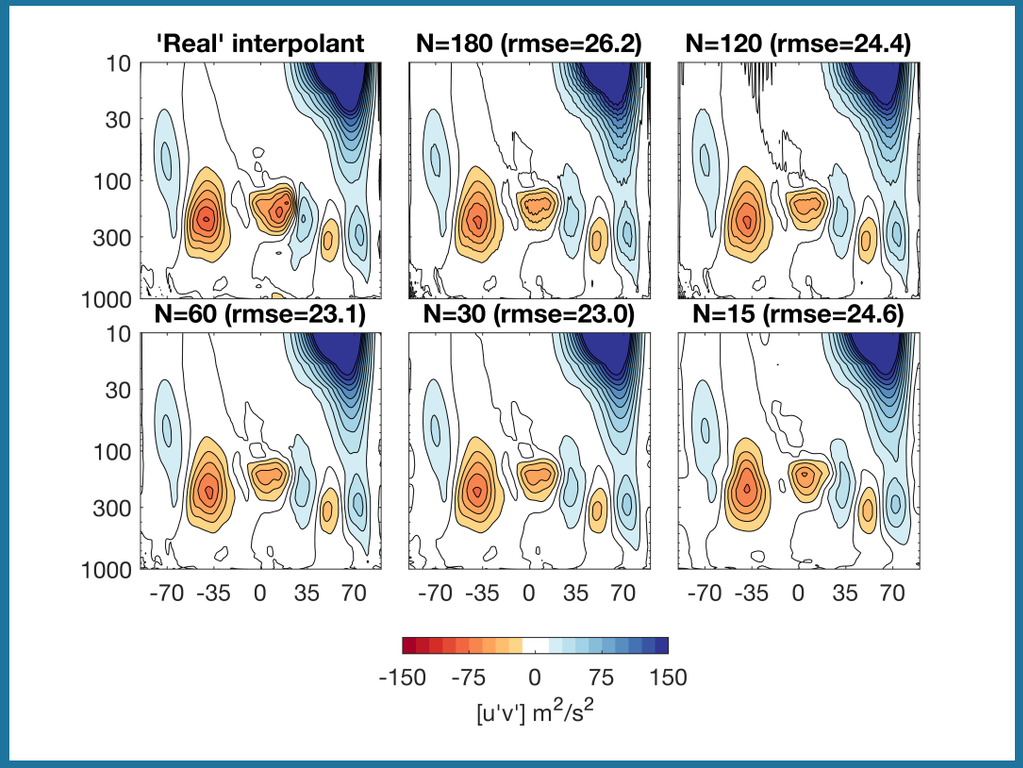

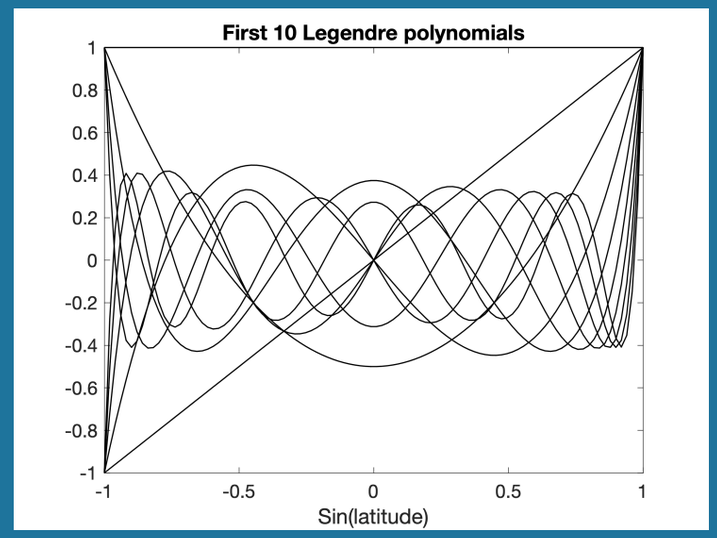

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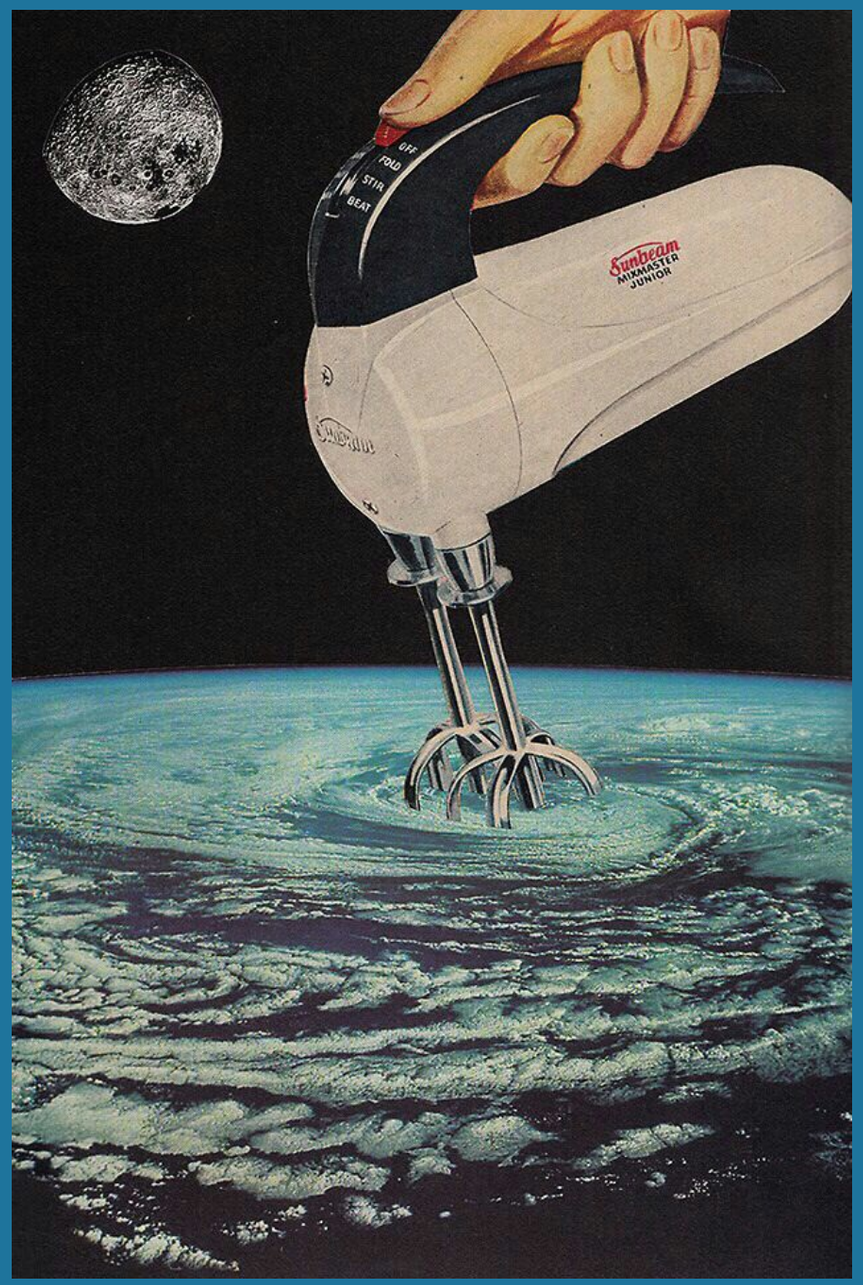
The future of climate modeling as a science tool



Current climate modeling paradigm

- Impose a forcing and see how the coupled atmosphere (or even earth) system evolves
- A diagnostic approach to understanding the global circulation is insufficient [Becker et al. 1997, Kim and Lee 2001, Davis and Birner 2019]
- Simple models will not solve this problem

Expand the capability of NCAR's models

- The greatest advantage of models is their ability to simulate the atmosphere the way it doesn’t work!
  - Fixed eddy simulations
  - Fixed zonal-mean simulations
  - Fixed chemical advection, production and loss

Summary

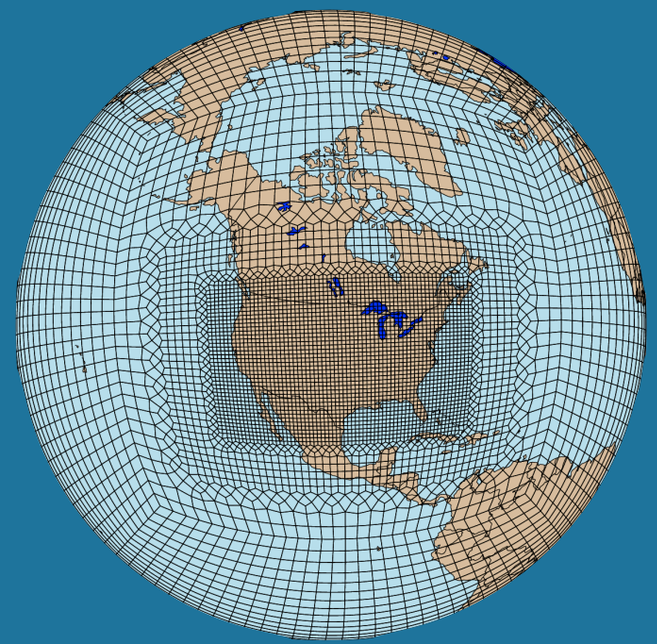
Key MUSICA features
- Refined mesh
- Modular parameterizations and components

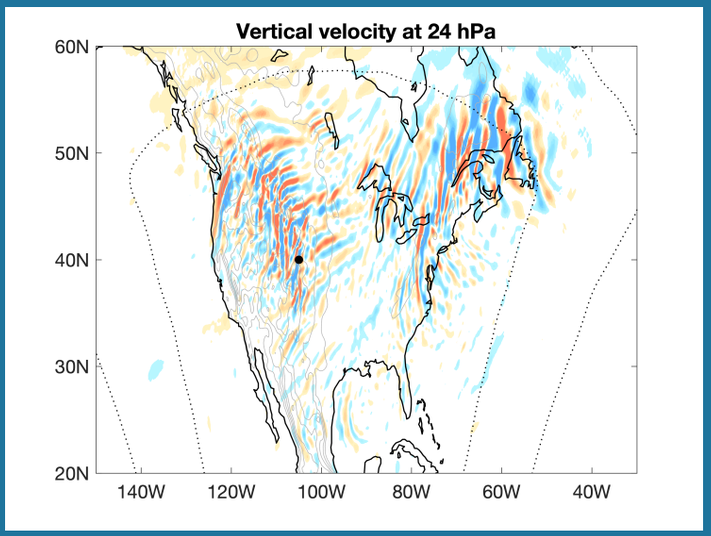
Impacts
- Resolve gravity waves, fine-scale horizontal transport
- Rapidly iterate mechanisms, “science” experiments

…At a fraction of the cost!

Challenges
- Resolve gravity waves
- Useful output on arbitrary meshes

Future
- Vertical refinement





(MUSICA) Whole Atmosphere Working Group

Co-chairs:

- Nicholas Davis (ACOM)
- Lorenzo Polvani (Columbia University)
- John Plane (University of Leeds)

We will be sending out an implementation plan for MUSICA (Whole Atmosphere) shortly.

Want to get involved, give feedback, or contribute ideas?
nadavis@ucar.edu