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Addressing Model Interface Challenges in E3SM

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With contributions from other members of the PAESCAL SciDAC-5 project team

Focus of this presentation

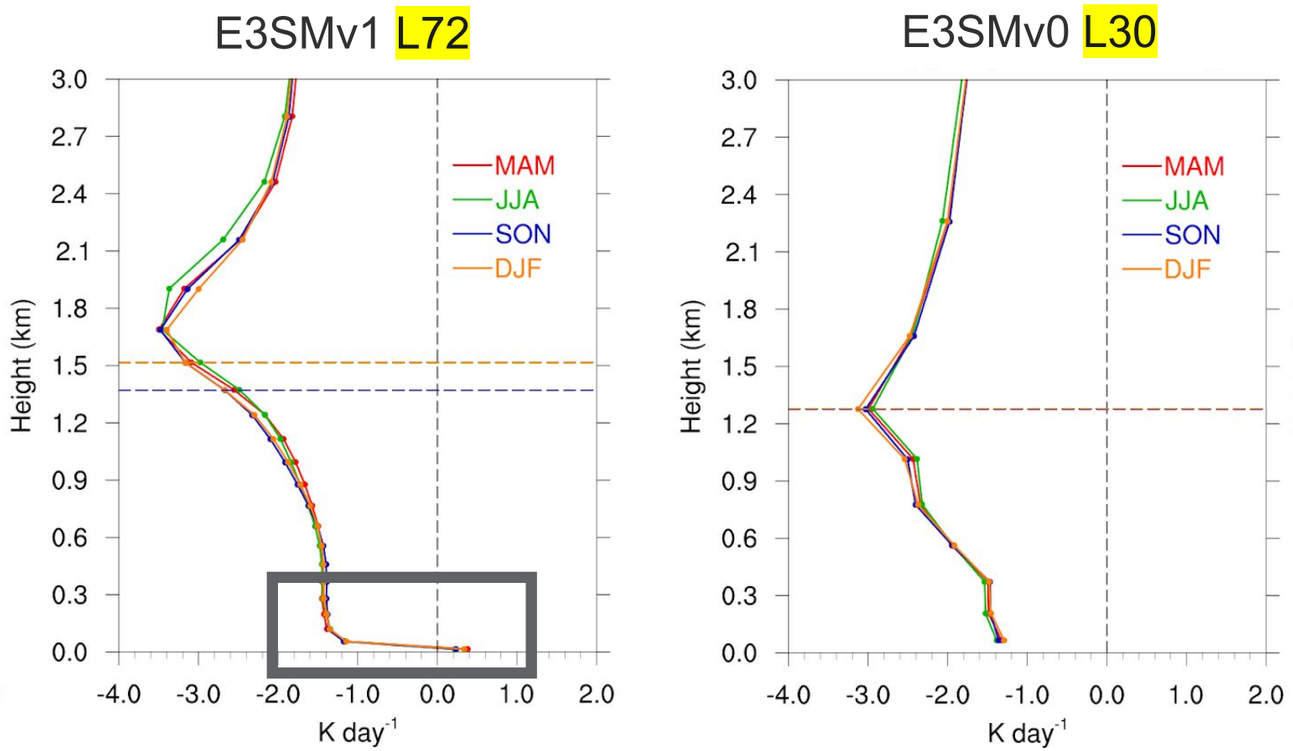
- Numerical coupling of physical processes near the Earth's surface in the atmosphere model
- Linkage to questions about the physical assumptions

Key messages

- Solving interface-related process equations in isolation and coupling them over long timesteps can be problematic
- Splitting-induced errors can be very sensitive to process ordering, vertical resolution, and timestep size
- It will be useful to couple interacting processes more tightly, part of which requires clarifying physical assumptions at the interface

Big jumps in near-surface QRL in E3SMv1

Seasonally averaged, ocean mean atmospheric longwave heating profiles

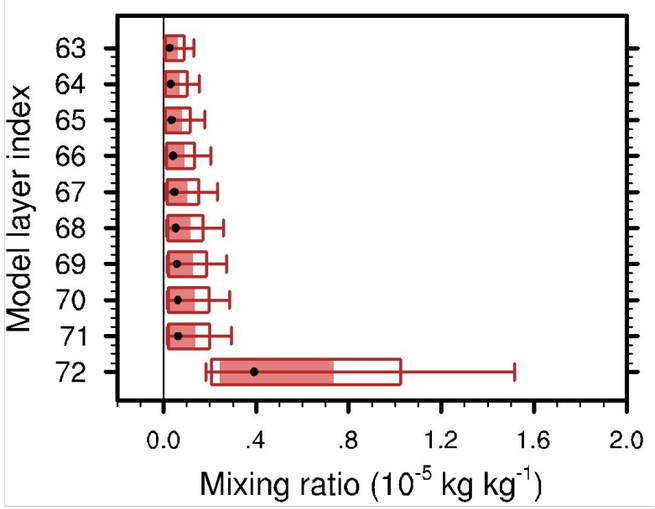


Figures by Shixuan Zhang (PNNL)

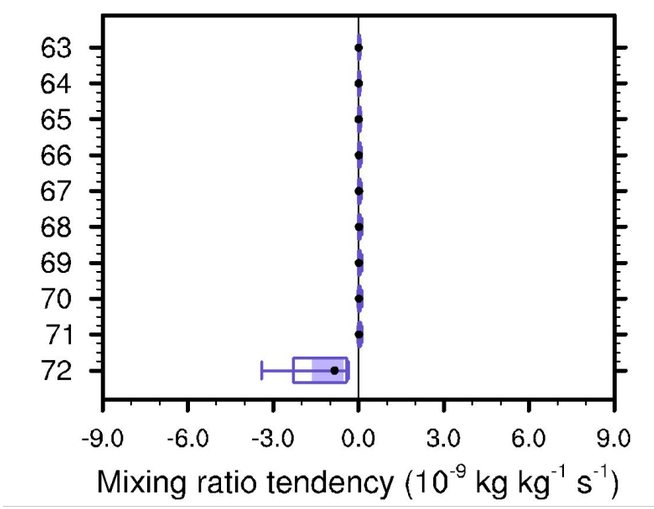
Big jumps in fields related to dust life cycle

Statistical distributions of instantaneous values in dust source regions in E3SMv1 L72

Mass mixing ratios passed as input to aerosol dry removal parameterization



Mass mixing ratio tendencies due to turbulent mixing



Figures from Wan et al. (2023, arXiv:2306.05377)

Origins of the jumps

- Physics in the surface layer
- Justifiable numerical artifacts
- Large, undesirable numerical errors caused by
  - Considering physical processes in isolation using sequential splitting
  - Long timesteps (e.g., 30 min at 1 degree)
  - Suboptimal process ordering

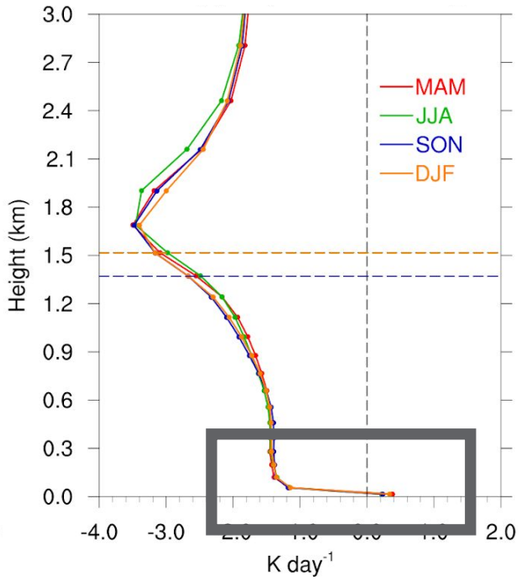
Impacts of process coupling errors in near-surface layers

Strong sensitivities of model results to

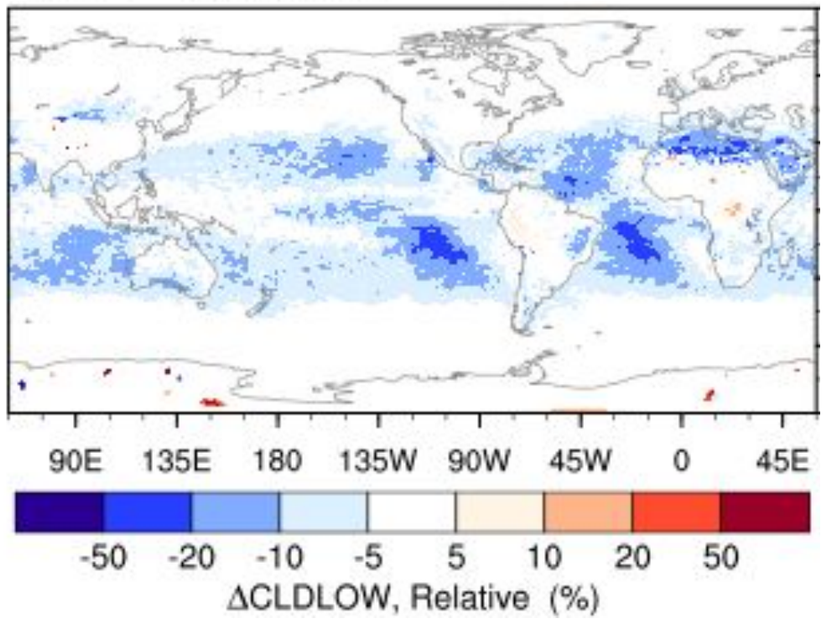
- Process ordering
- Vertical resolution
- Timestep size

Near-surface jumps in QRL make low-cloud fraction sensitive to the ordering of radiation and deep convection

Seasonal mean ocean mean QRL



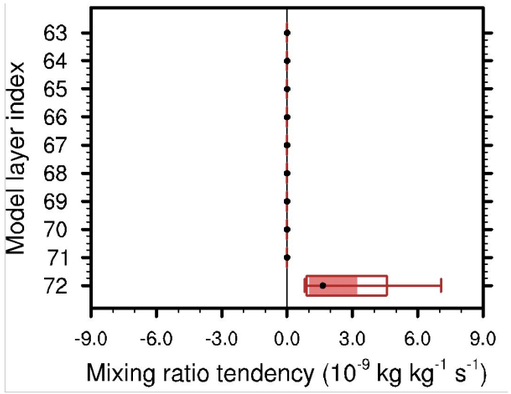
Relative changes in annual mean low-cloud fraction (CLDLOW) if radiation dT/dt is applied after instead of before deep convection



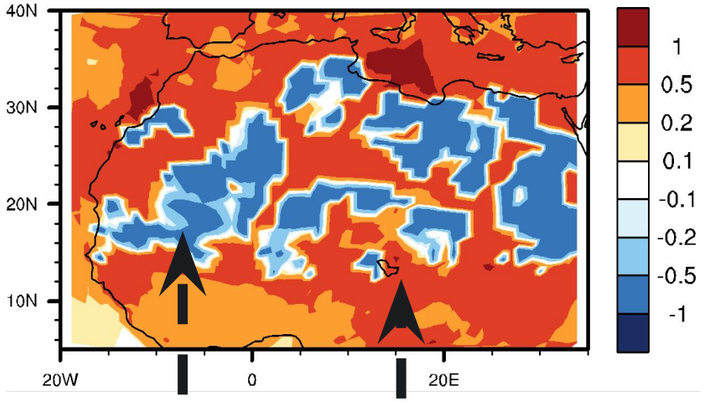
Figures by Shixuan Zhang (PNNL)

Near-surface jumps caused by emissions can make aerosol life cycle sensitive to process ordering and vertical resolution

Dust mass mixing ratio tendency due to surface emissions in L72



Relative changes in annual mean dust dry removal in bottom layer caused by process ordering change, E3SMv1 L72



Increase/decreases exceeding 50%

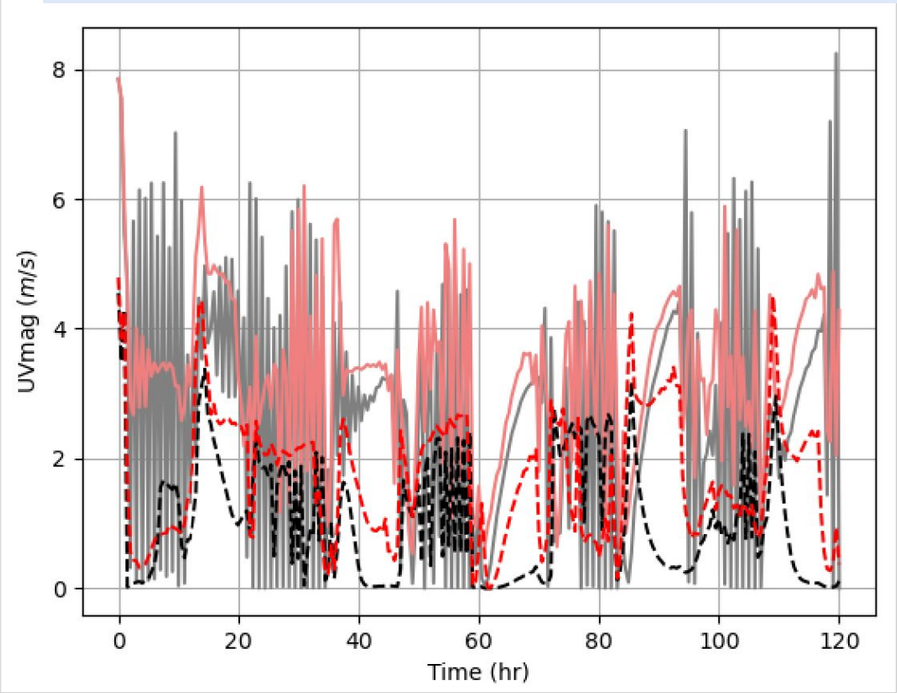
Relative changes in global averages, E3SMv1 L30 vs. L72

	Burden change	Lifetime change
Dust	+39%	+37%
Sea salt	+52%	+53%

Figures and numbers from Wan et al. (2023, arXiv:2306.05377)

Jumps in time in near-surface wind speed are sensitive to timestep size, process ordering, and the way how surface momentum fluxes are calculated and applied to the atmosphere

Time series of wind speed in bottom layer in various E3SMv1 L72 simulations



- Gray: original model
- Pink: with revised surface drag code
- Black dashed: with revised process ordering
- Red dashed: with revision in both surface drag and process ordering

From Sean Patrick Santos (PNNL)

In older model versions when the bottom layer in an AGCM was ~100 m thick, the surface was viewed as

- The lower boundary of the atmosphere
- A source of external forcing

How things may be improved in the future

- Also consider the surface layer with strong sources/sinks and short time scales
- Revise numerical coupling of related processes

Our work in E3SM

- Lessons learned
  - Avoid sequentially split source and sink over long timesteps if one significantly affects the other
  - Parallel splitting of source and sink can be an easy and effective remedy (but we can do better)

- Current work
  - Not only reorder, but also reorganize parameterizations at the `tphysbc/tphysac` level
    (E.g., separate different dry removal processes; combine turbulent mixing with emissions and some other processes)
  - Explore more sophisticated coupling schemes beyond simple sequential and parallel splitting

Linkage to questions about physical assumptions

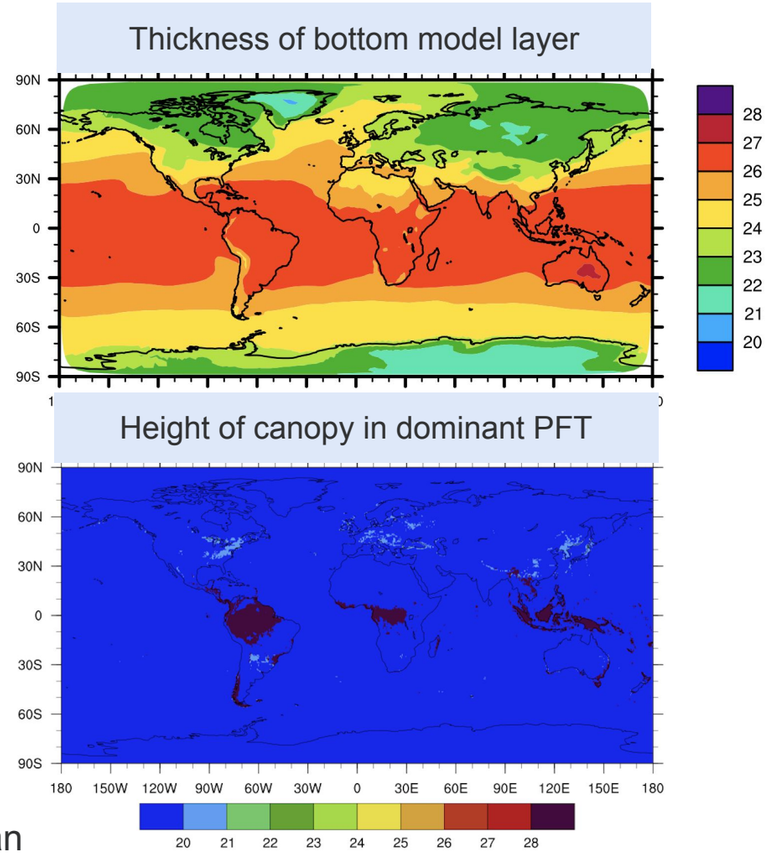
- Guiding principle of our numerical coupling work:
  respect and try to faithfully represent the physics described by the undiscretized equations

  ⇒ Before revising any coupling schemes, we need to clarify whether the equations will change soon

Example: turbulent dry deposition of aerosols

- Should this processes occur in multiple model layers in the future?
  - Valid question because of interception by forest canopy
  - If the atmosphere model's lower boundary is at the ground, then some canopies are already intruding into the second lowest layer (see figures)
  - But some colleagues defined the canopy top as the atmosphere model's lower boundary

  ⇒ What do these imply for aerosol dry deposition?



We expect to run into more questions like this soon

- Collaborations with experts on interface physics will be crucial

Figures by Michael Brunke and Hui Wan