Revised Process Coupling Reduces Time-step Sensitivities in Subtropical Low Clouds in EAMv1

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Background

- SciDAC project addressing time integration errors associated with EAM’s physics parameterizations in individual parameterizations and process coupling
- Strong time-step sensitivities in model climate indicate opportunities for improvement

Differences in 10-year averages, $\Delta t/6$ – v1_CTRL, 1 degree resolution

Total cloud cover

Net cloud radiative forcing (CF)

Wan et al. (2021, doi: 10.5194/gmd-14-1921-2021)
Shortening EAMv1’s time steps to 1/6 of the default causes a systematic increase in model biases.

Model biases in 10-year mean present-day climate, 1 degree resolution

See also Wan et al. (2021, doi: 10.5194/gmd-14-1921-2021)
Reducing time-step sensitivity can have practical benefits for multi-resolution configurations, e.g., RRM

- V2 RRM uses **hybrid time stepping** (high-res dycore + low-res physics, *Tang et al. 2020*)
- Shorter $\Delta t_{\text{phy}}$ would lead to
  - Significant changes in the atmospheric energy balance
  - Need for re-tuning of empirical parameters (tedious!)

*Figures from Qi Tang et al., “Regionally refined model updates for the E3SMv2 atmosphere model”, Oct. 2020, ESMD/E3SM PI Meeting. Courtesy Qi Tang @LLNL*
Attributing and understanding time-step sensitivities

Weakened SWCRE due to shortening of time step from 30 min to 5 min

Coupling between cloud macro-/microphysics and rest of model

Coupling of radiation, deep convection, and shallow convection

Shallow cumulus and stratiform cloud macro/microphysics

Other step sizes and coupling frequencies.

Planned investigation: coupling frequency and closure formulation for deep convection (with Guang Zhang)

Wan et al. (2021, doi: 10.5194/gmd-2020-330)
Two modifications we made to process coupling in EAMv1

- No change in $\Delta t$ for any parameterization or dynamics
- Negligible computational cost
- Distinct impacts on subtropical low clouds

Resulting changes in annual mean SWCF
What is the combined effect?

Can they significantly reduce time-step sensitivities in the low latitudes?

Four 10-year simulations with climatological SST

- EAMv1 control vs revised coupling
- $\Delta t_{phy} = 30$ min vs 5 min
Layout of the next few slides

- EAMv1 control, 5 min vs 30 min (Time-step sensitivity in v1 control)
- EAMv1 revised, 5 min vs 30 min (Time-step sensitivity in v1 revised)
- Revised vs control, $\Delta t_{\text{phy}} = 30$ min (Impact at default $\Delta t_{\text{phy}}$)
- Revised vs control, $\Delta t_{\text{phy}} = 5$ min (Do they converge to the same solution? Have we changed the model physics?)

- All plots are 10-year averages
- Statistically insignificant results masked out in white
Low-cloud fraction

V1 control, 5 min minus 30 min

V1 revised, 5 min minus 30 min

revised vs control, $\Delta t_{\text{phy}} = 30$ min

revised vs control, $\Delta t_{\text{phy}} = 5$ min
Net cloud forcing (SWCF+LWCF)

V1 control, 5 min minus 30 min

V1 revised, 5 min minus 30 min

revised vs control, $\Delta t_{\text{phy}} = 30$ min

revised vs control, $\Delta t_{\text{phy}} = 5$ min
Longwave cloud forcing (LWCF)

V1 control, 5 min minus 30 min

V1 revised, 5 min minus 30 min

revised vs control, $\Delta t_{\text{phy}} = 30$ min

revised vs control, $\Delta t_{\text{phy}} = 5$ min
Large-scale precipitation (PRECL)

V1 control, 5 min minus 30 min

V1 revised, 5 min minus 30 min

revised vs control, $\Delta t_{phy} = 30$ min

revised vs control, $\Delta t_{phy} = 5$ min
Summary and outlook

• The two changes in process coupling, when combined, significantly reduce time-step sensitivities in subtropical low clouds in EAMv1

• Computational cost is negligible (no change in $\Delta t$ for any parameterization or dynamics)

• Code changes are simple and non-intrusive (only in $t_{\text{physbc}}$, $t_{\text{physac}}$, and $\text{clubb\_tend\_cam}$)

• Remaining sensitivities are primarily associated with deep convection and high clouds
  - Coupling frequency and closure formulation in deep convection parameterization (with Guang Zhang)
  - Ice microphysics?
Thoughts to discuss with the E3SM team

- Test the revised coupling for v3?
- RRM will probably need to continue using hybrid time-stepping until remaining sensitivities are addressed

- Include time-step sensitivity testing as part of model evaluation process
  - E.g., as new parameterizations come in
  - Nudged 3-month simulations can already be very informative (⇒ low cost)

- It’s time to re-work process ordering and coupling
  - Current scheme is suboptimal for a number of atmospheric processes and prognostic variables
  - Problems will likely get worse when vertical resolution is further increased
  - New atmosphere driver (AD) in development for v4 can provide an excellent opportunity for this

Thanks for your attention!

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