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

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With contributions from Kai Zhang[1] and Huiping Yan[7]
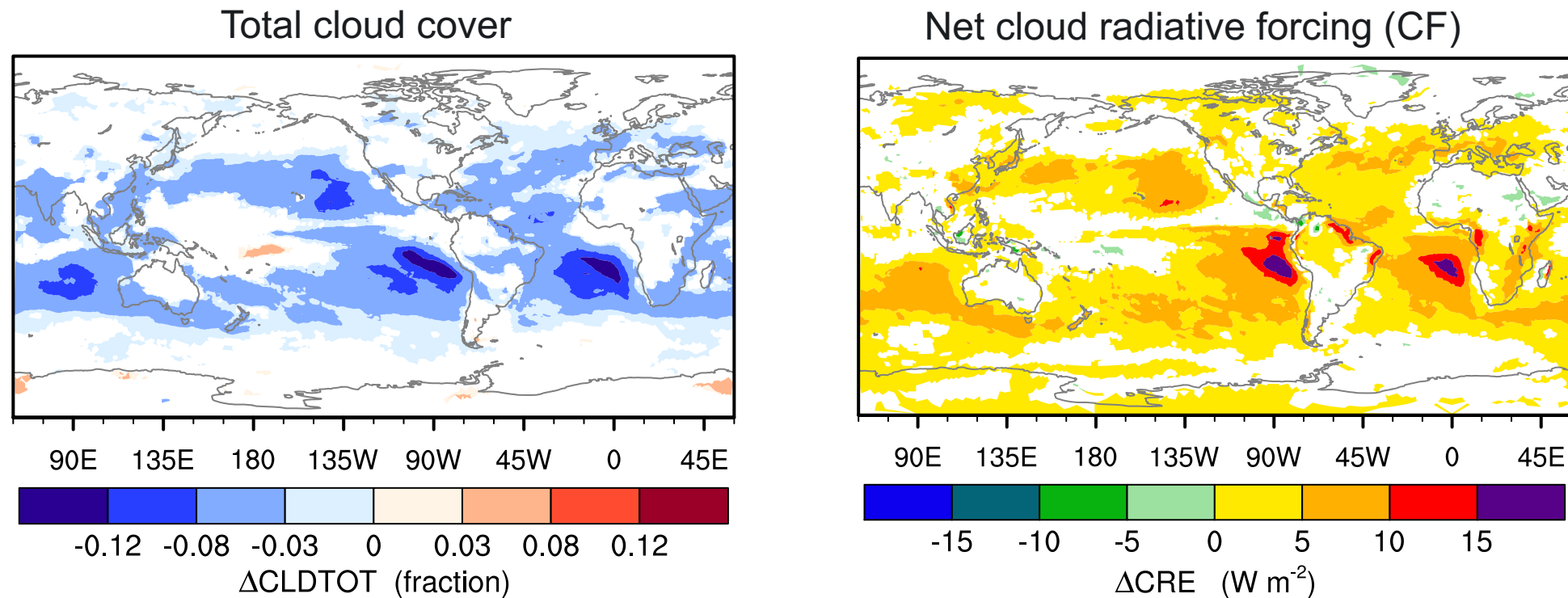
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Background

- SciDAC project addressing the ~~numerical~~ ~~resolution~~ with EAM's physical parameterizations in individual param~~eters~~

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

Total cloud cover

Net cloud radiative forcing (CF)

Global mean: -22.11   (d) DT/6 — CNTL   Global mean: 3.04   (e) (DT/6 — CNTL)/ CNTL Global mean: -11.68

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
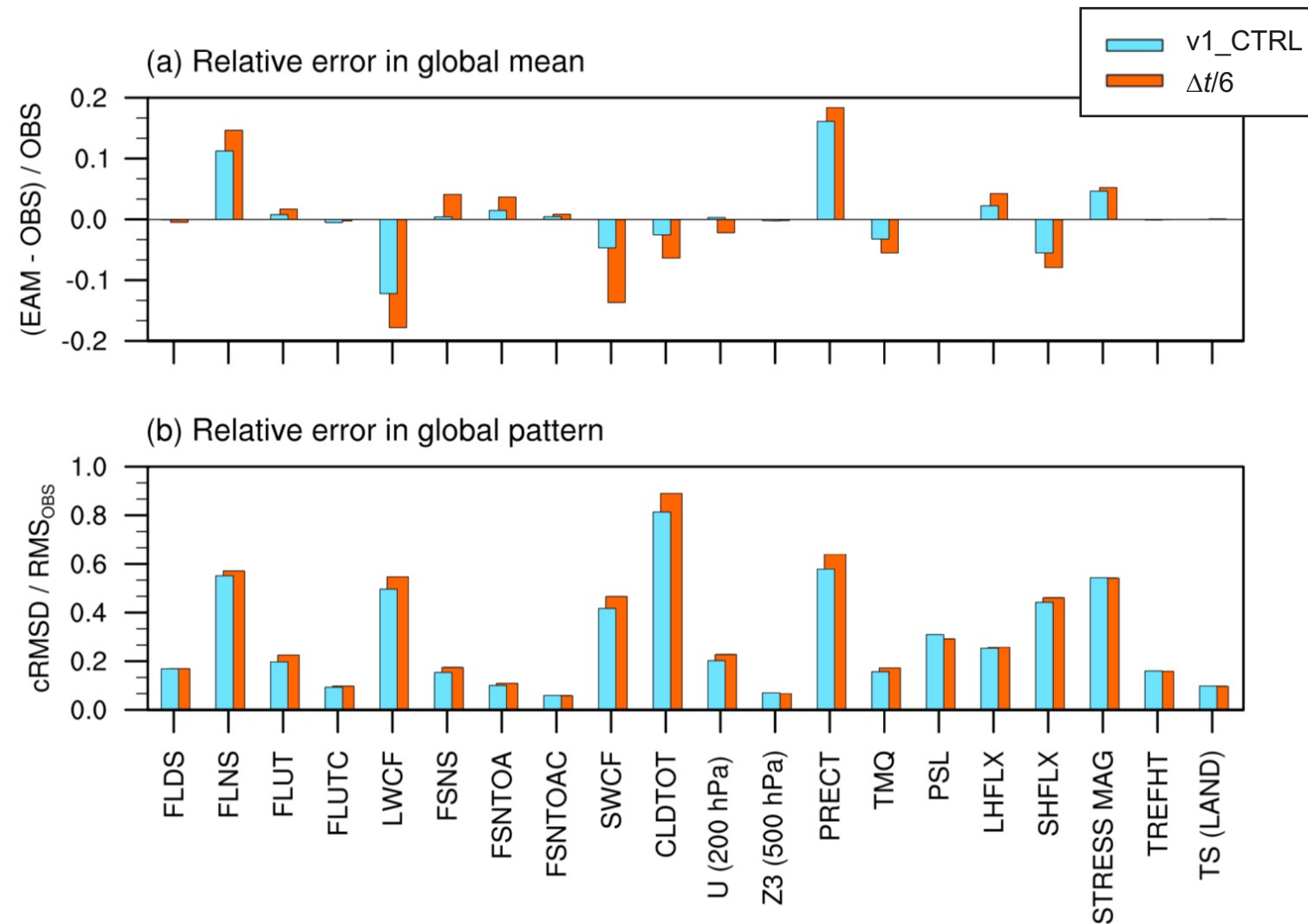
See also Wan et al. (2021, doi: 10.5194/gmd-14-1921-2021)

Reducing time-step sensitivity can have practical resolution configurations, e.g., RRM

- V2 RRM uses **hybrid time-stepping** (high-res dycore + low-res physics, *Tang et al. 2020*)

- Shorter Δt_{phy} would lead to
  - Significant changes in the atmospheric energy balance
  - Need for re-tuning of empirical parameters (tedious!)

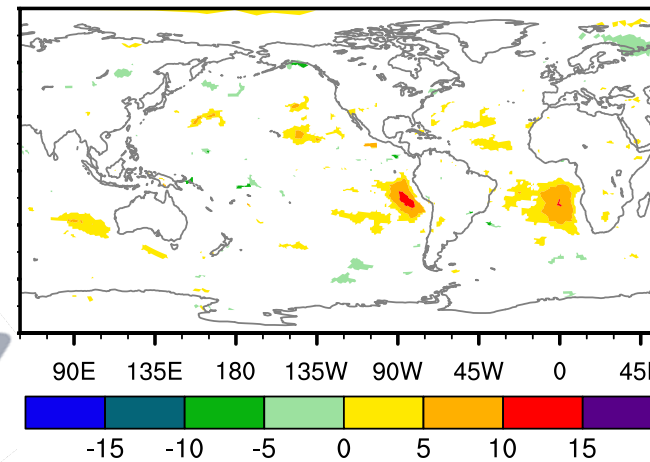RRM – ne30 when using 0.5x physics dt
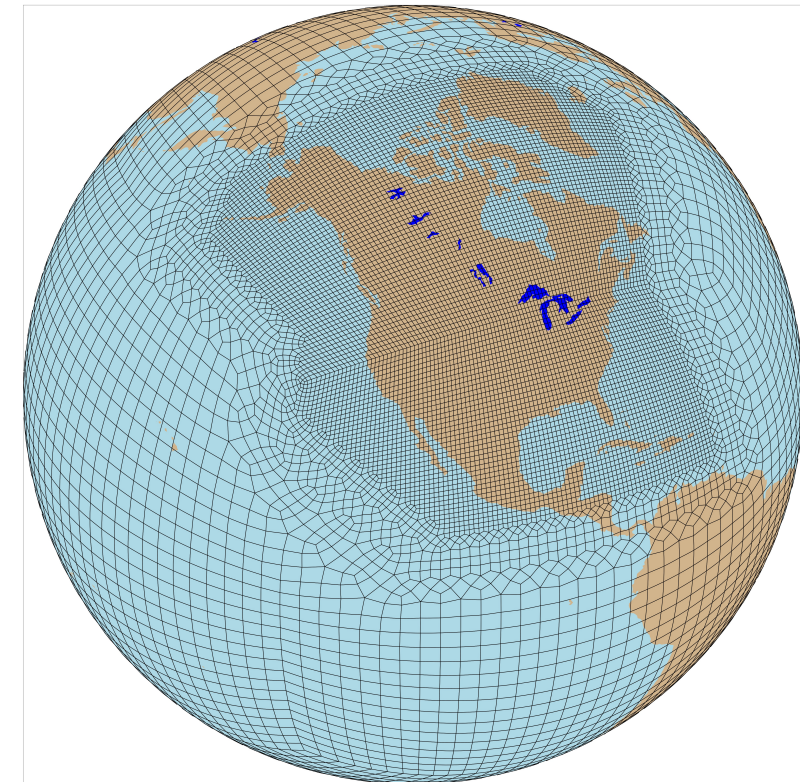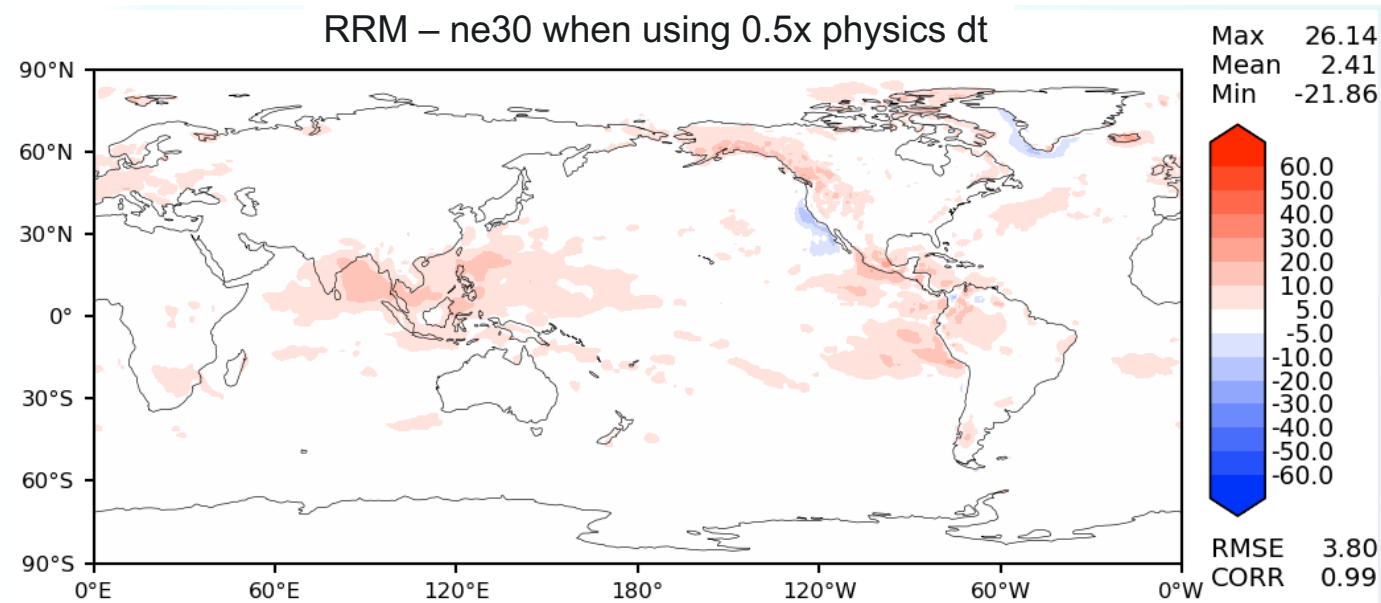
Figures from Qi Tang et al., "Regionally refined model updates for the E3SMv2 atmosphere model," Oct. 2020, ESMD/E3SM PI Meeting. Courtesy Qi Tang @LLNL

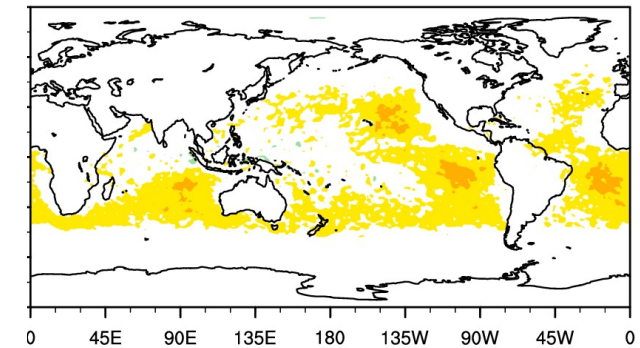# Attributing and understanding time-step sensitivities

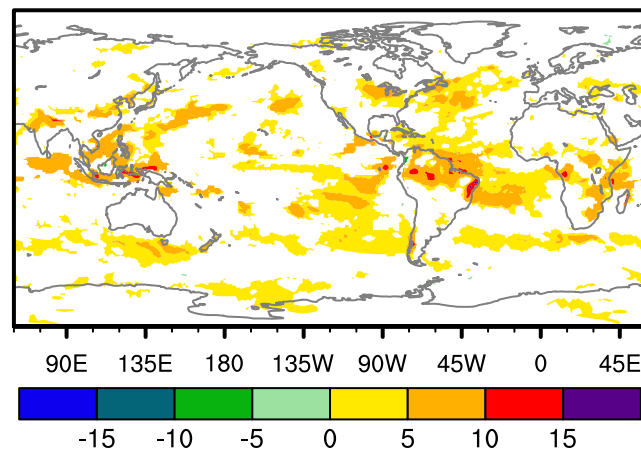Weakened SWCRE due to shortening of time step from 30 min to 5 min
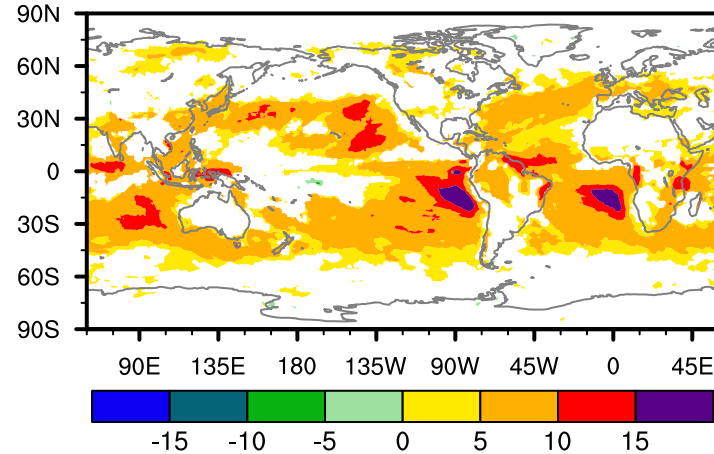
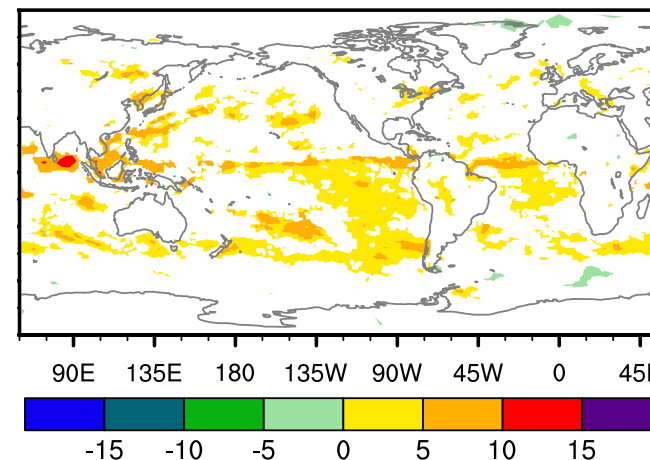Coupling between cloud macro-/microphysics and rest of model

Coupling of radiation, deep convection, and shallow convection
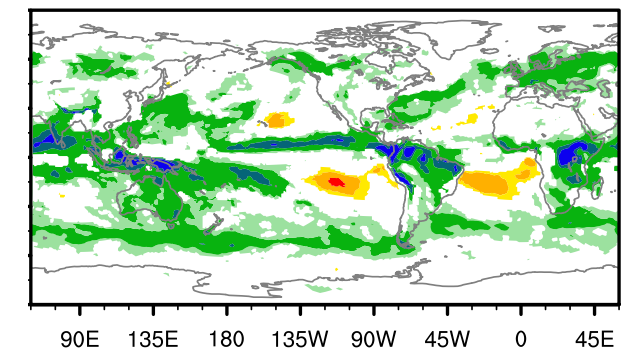

Shallow cumulus and stratiform cloud macro/microphysics

Other step sizes and coupling frequencies.


$\Delta t/\tau$ in deep convection

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

Two modifications we made to process coupling in EAMv1

- No change in Δt for any parameterization or dynamics
- Negligible computational cost
- Distinct impacts on subtropical low clouds

Resulting changes in annual mean SWCF

Modification #1

Modification #2
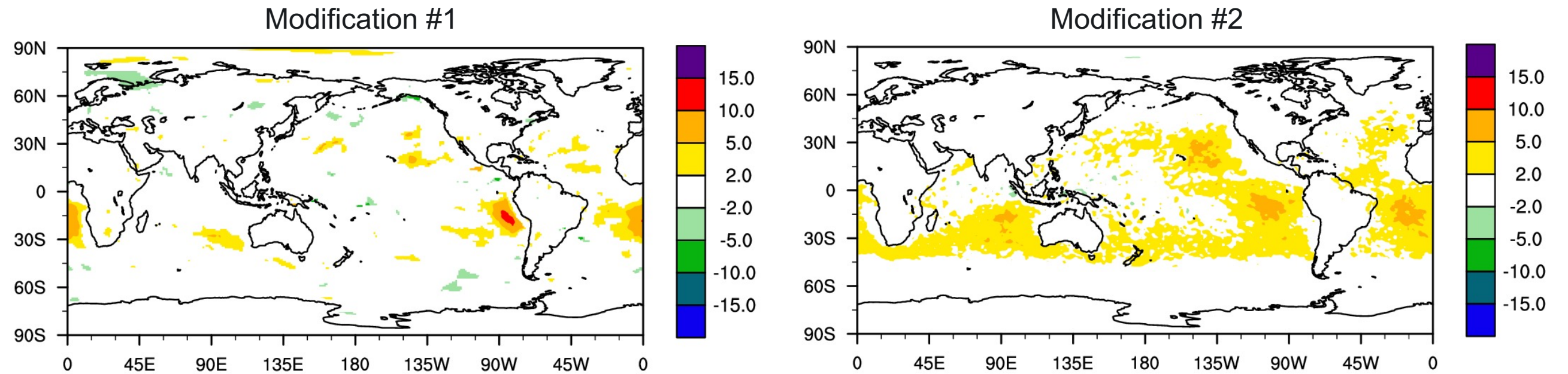
What is the combined effect?

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

Four 10-year simulations with climatological SST

- EAMv1 control vs revised coupling
- Δt_{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)

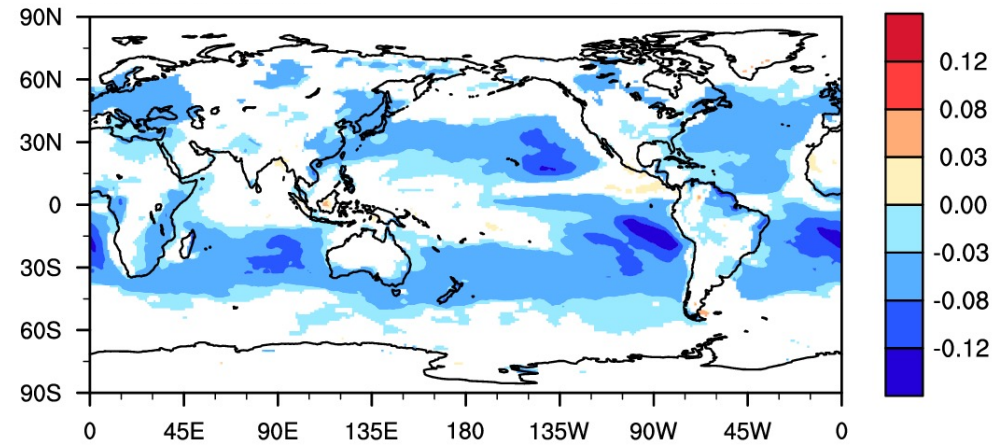Revised vs control, Δt_{phy} = 30 min
(Impact at default Δt_{phy})

Revised vs control, Δt_{phy} = 5 min
(Do they converge to the same solution?
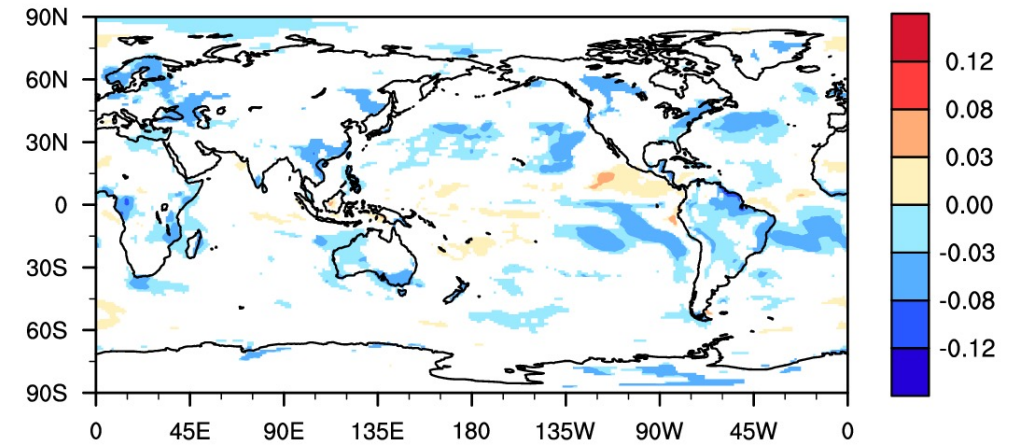Have we changed the model physics?)

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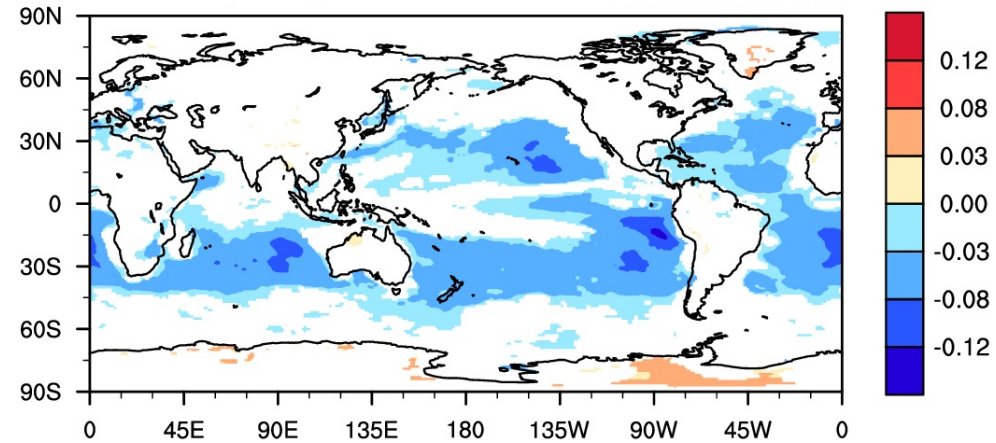- Statistically insignificant results masked out in white
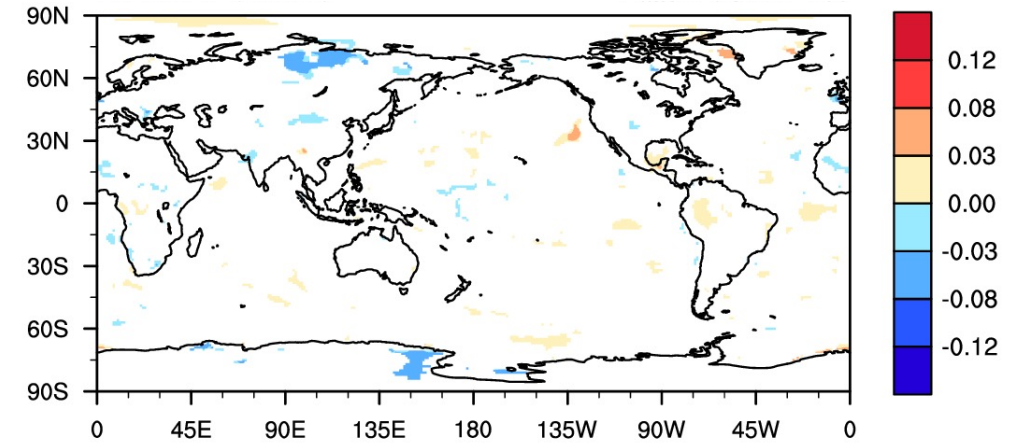
Low-cloud fraction

V1 control, 5 min minus 30 min

V1 revised, 5 min minus 30 min

revised vs control, Δt_{phy} = 30 min

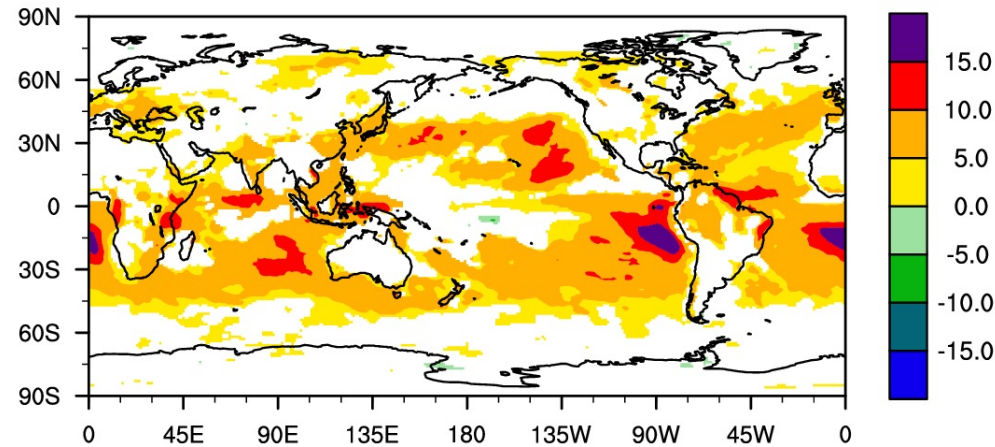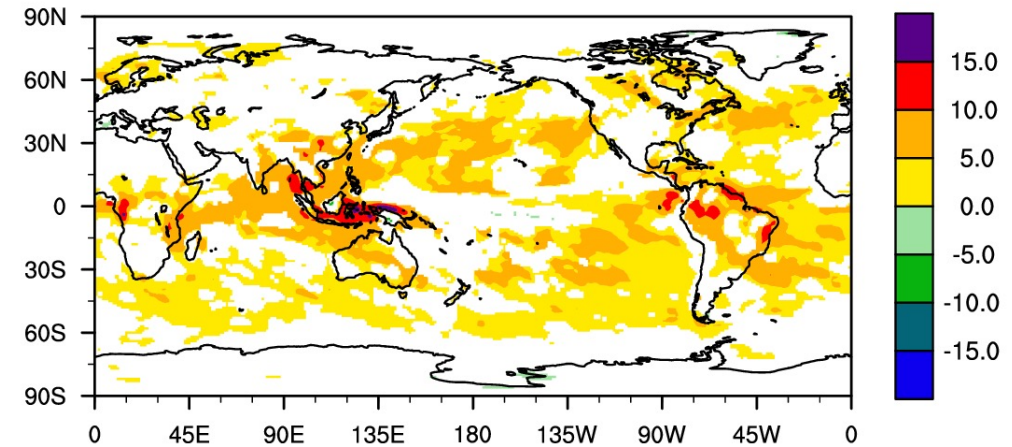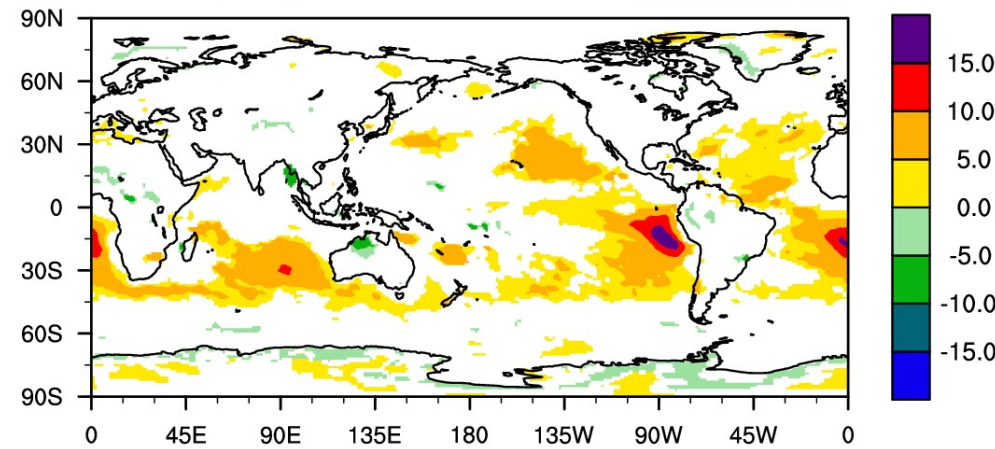revised vs control, Δt_{phy} = 5 min

Net cloud forcing (SWCF+LWCF)

V1 control, 5 min minus 30 min

V1 revised, 5 min minus 30 min

revised vs control, Δt_{phy} = 30 min

revised vs control, Δt_{phy} = 5 min

Longwave cloud forcing (LWCF)

V1 control, 5 min minus 30 min
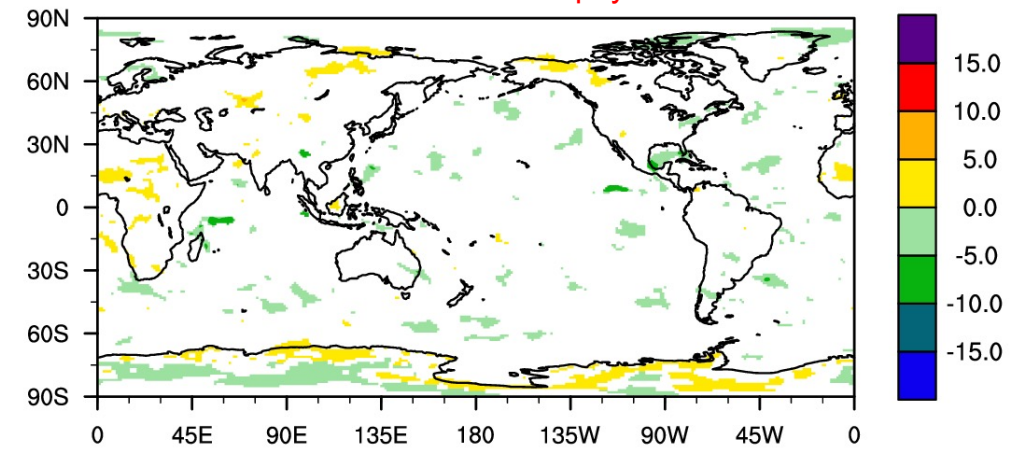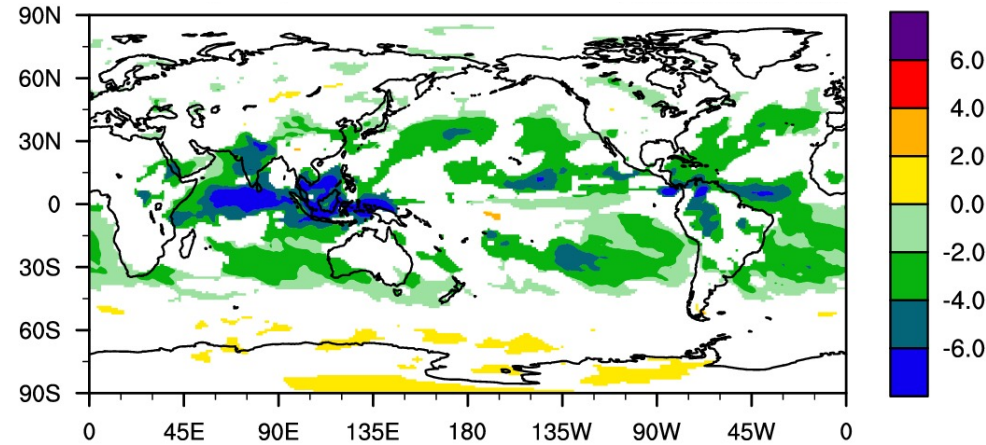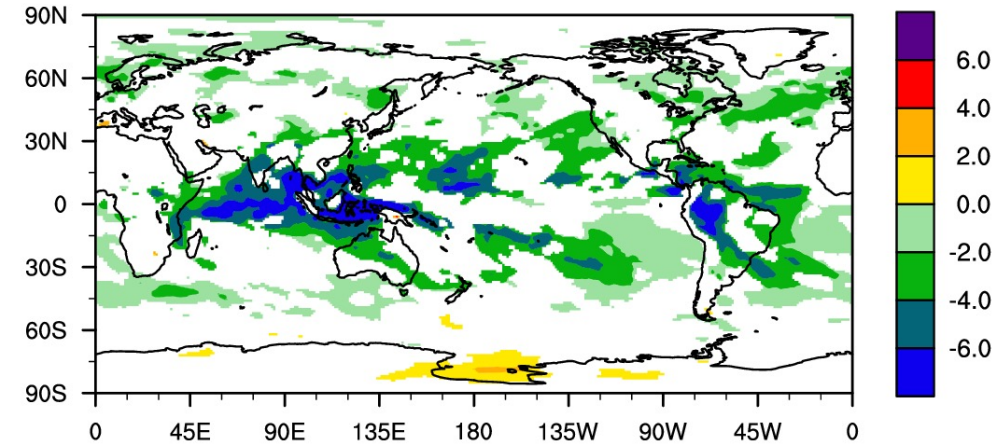

V1 revised, 5 min minus 30 min

revised vs control, Δt_{phy} = 30 min

revised vs control, Δt_{phy} = 5 min

Large-scale precipitation (PRECL)
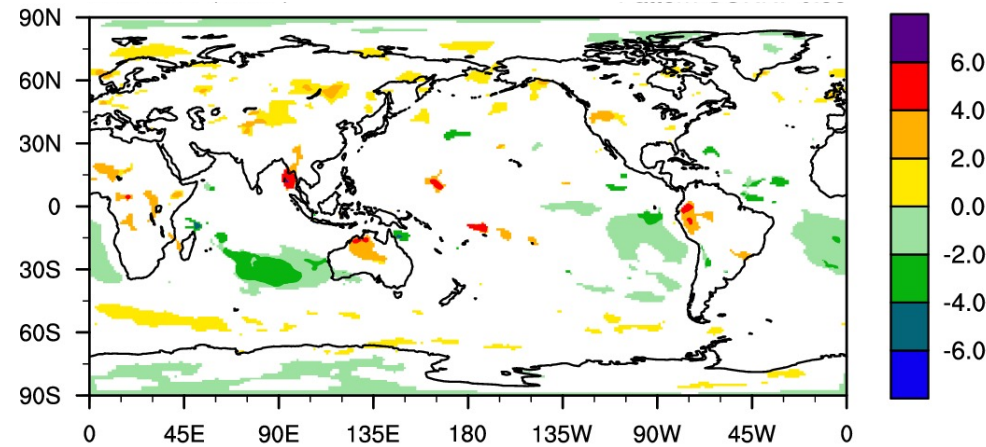

V1 control, 5 min minus 30 min
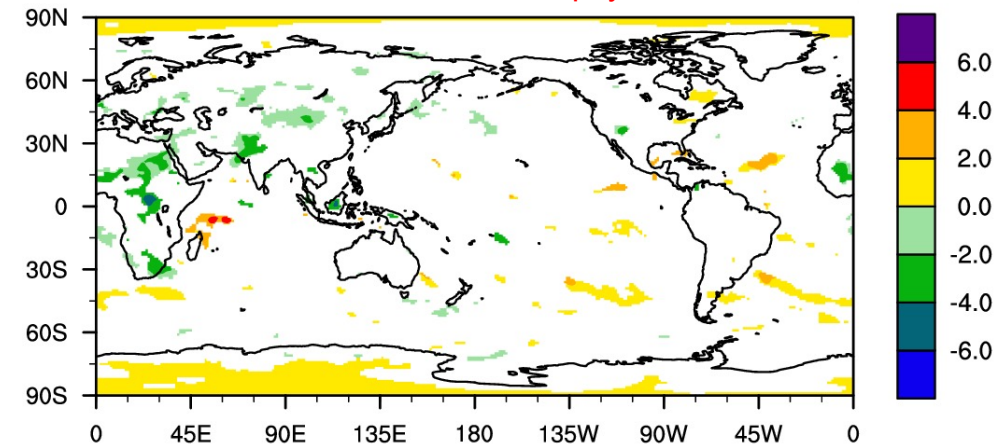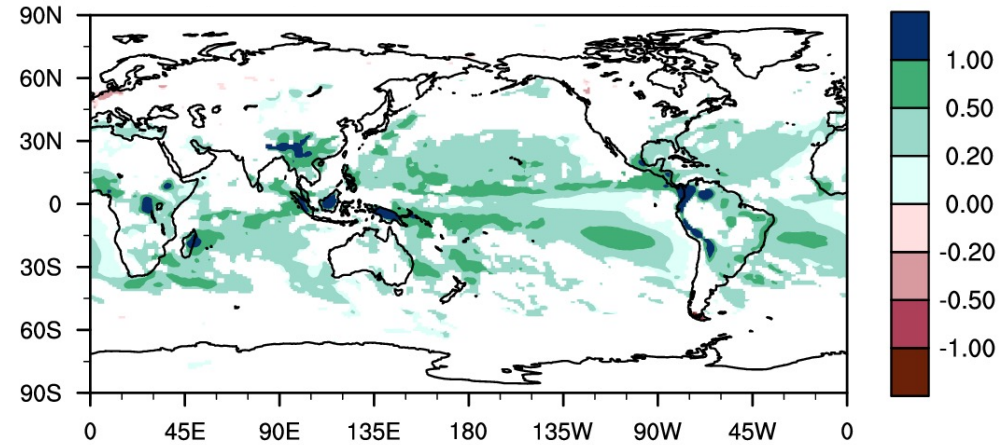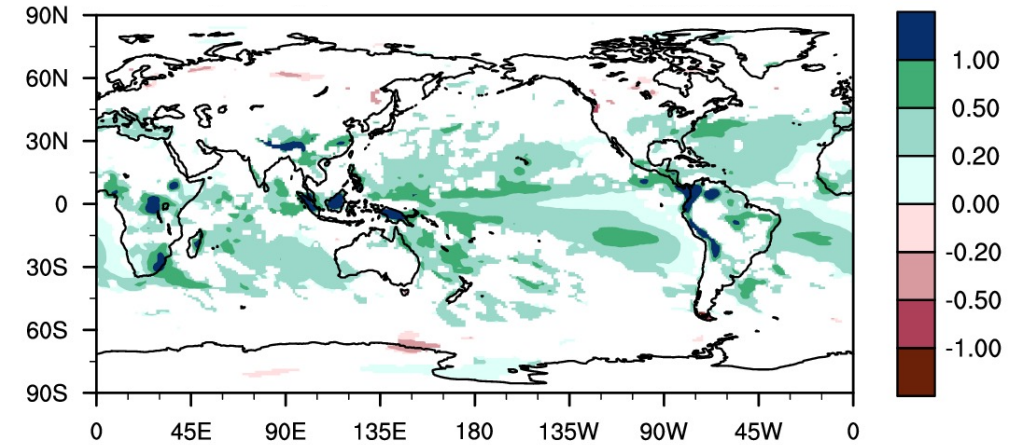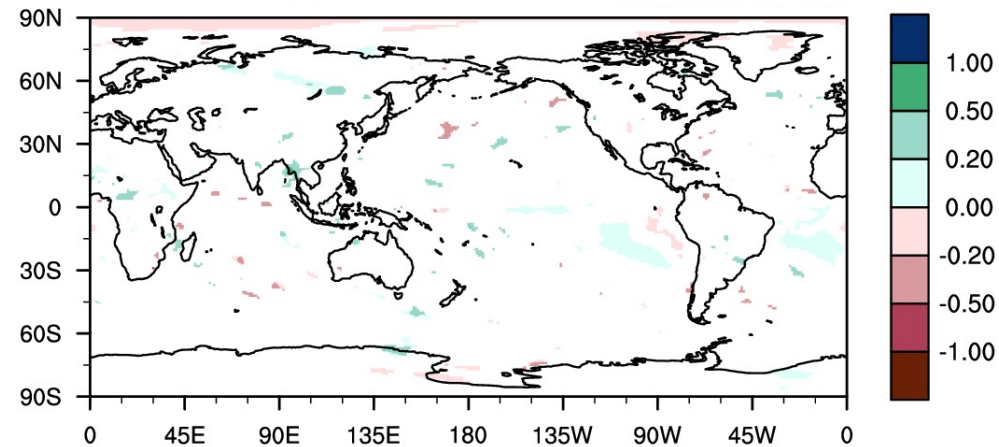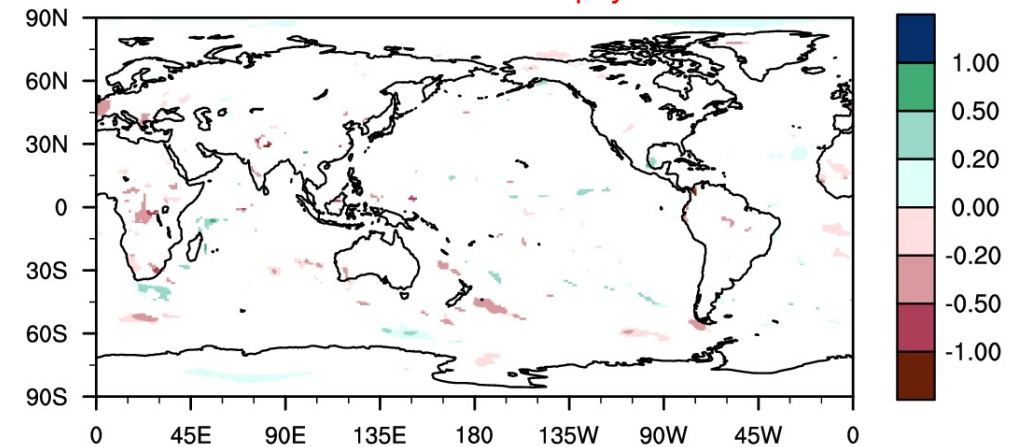
V1 revised, 5 min minus 30 min

revised vs control, Δt_{phy} = 30 min

revised vs control, Δt_{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 Δt for any parameterization or dynamics)

- Code changes are simple and non-intrusive (only in `tphysbc`, `tphysac`, and `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 ($\Rightarrow$ 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

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Thanks for your attention!

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