



Quantifying, Attributing, and Understanding Time Step Sensitivities in the E3SMv1 Atmosphere Model

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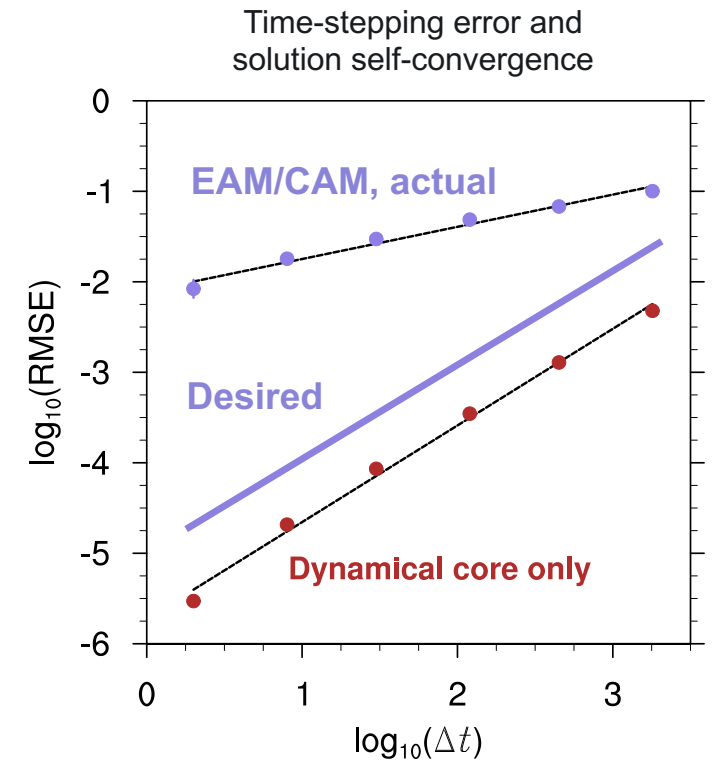
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Background and motivation

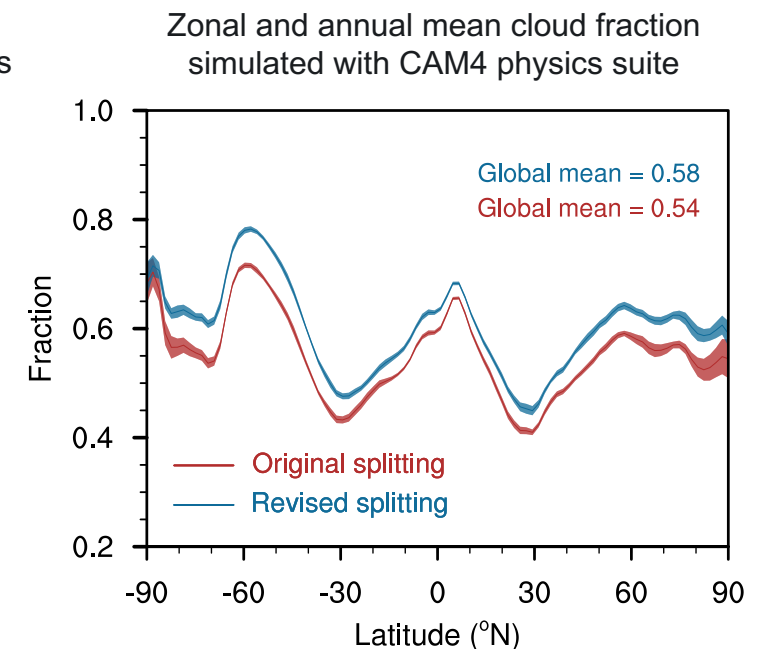
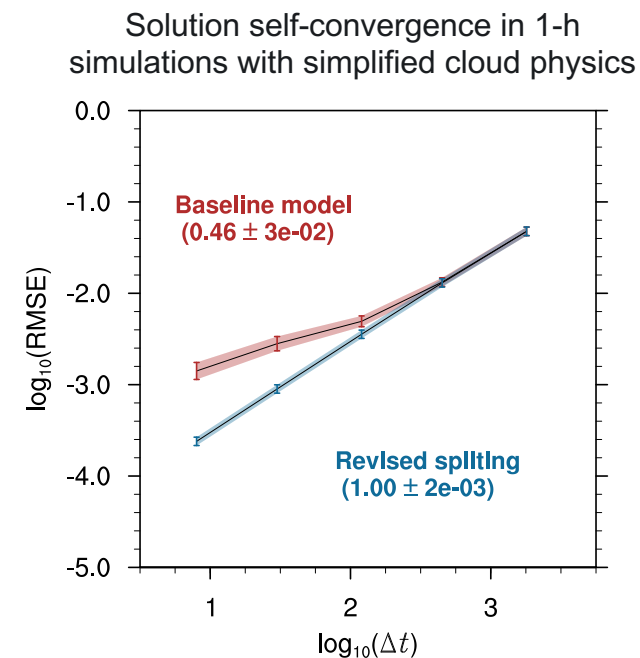
Various significant, undesirable numerical artifacts noticed in E3SM and similar models, both global and regional, at traditional and much higher resolutions

SciDAC project aiming at reducing time-stepping error and in atmospheric physics parameterizations in E3SM

- Investigations using simplified models demonstrated the feasibility and benefits of addressing time-step convergence issues
- From proofs of concept to the “real EAM”
 - **Priorities?**
 - **Relevance to day-to-day development focused on reducing model biases?**

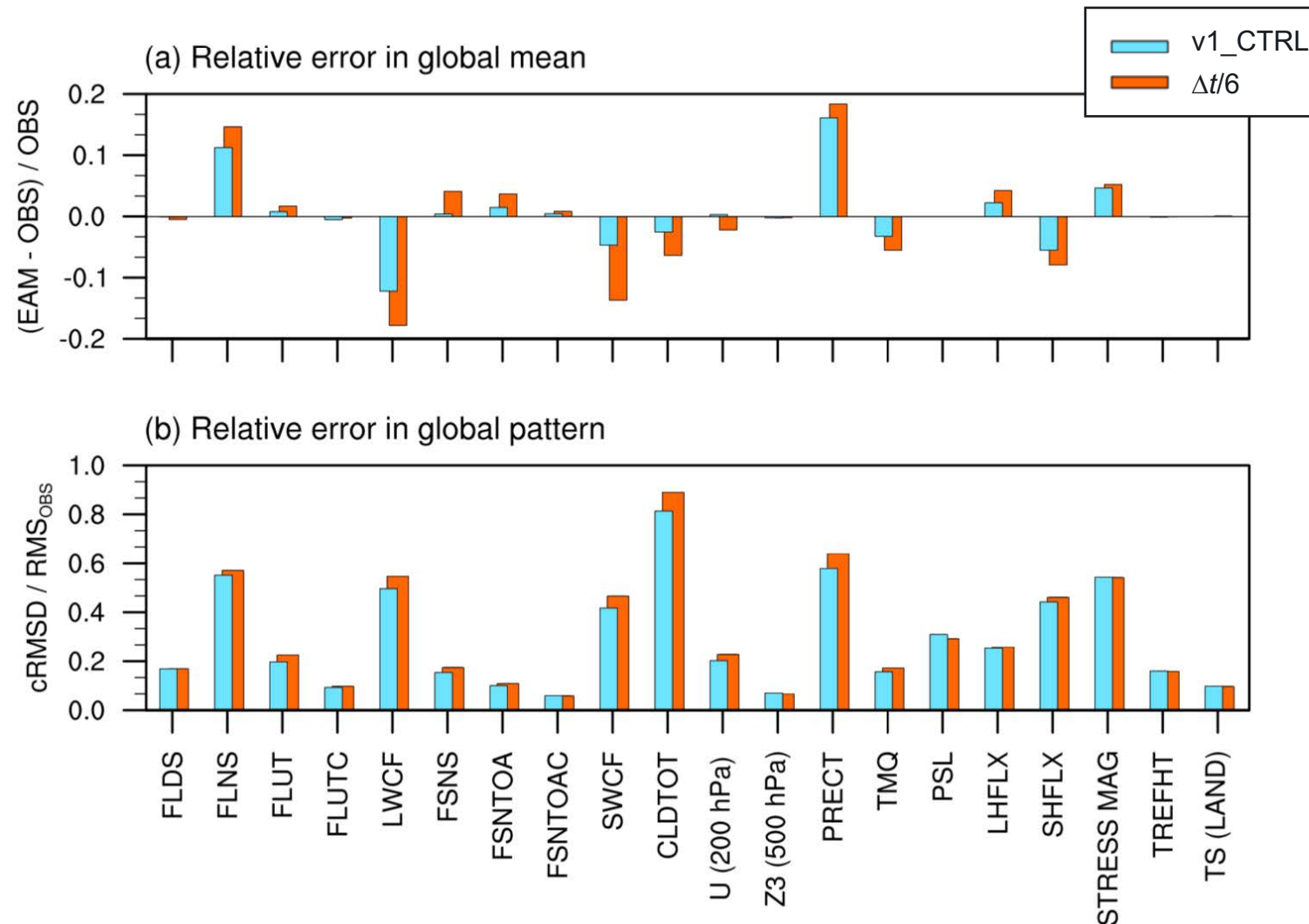


See also Wan et al. (2015, JAMES)



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



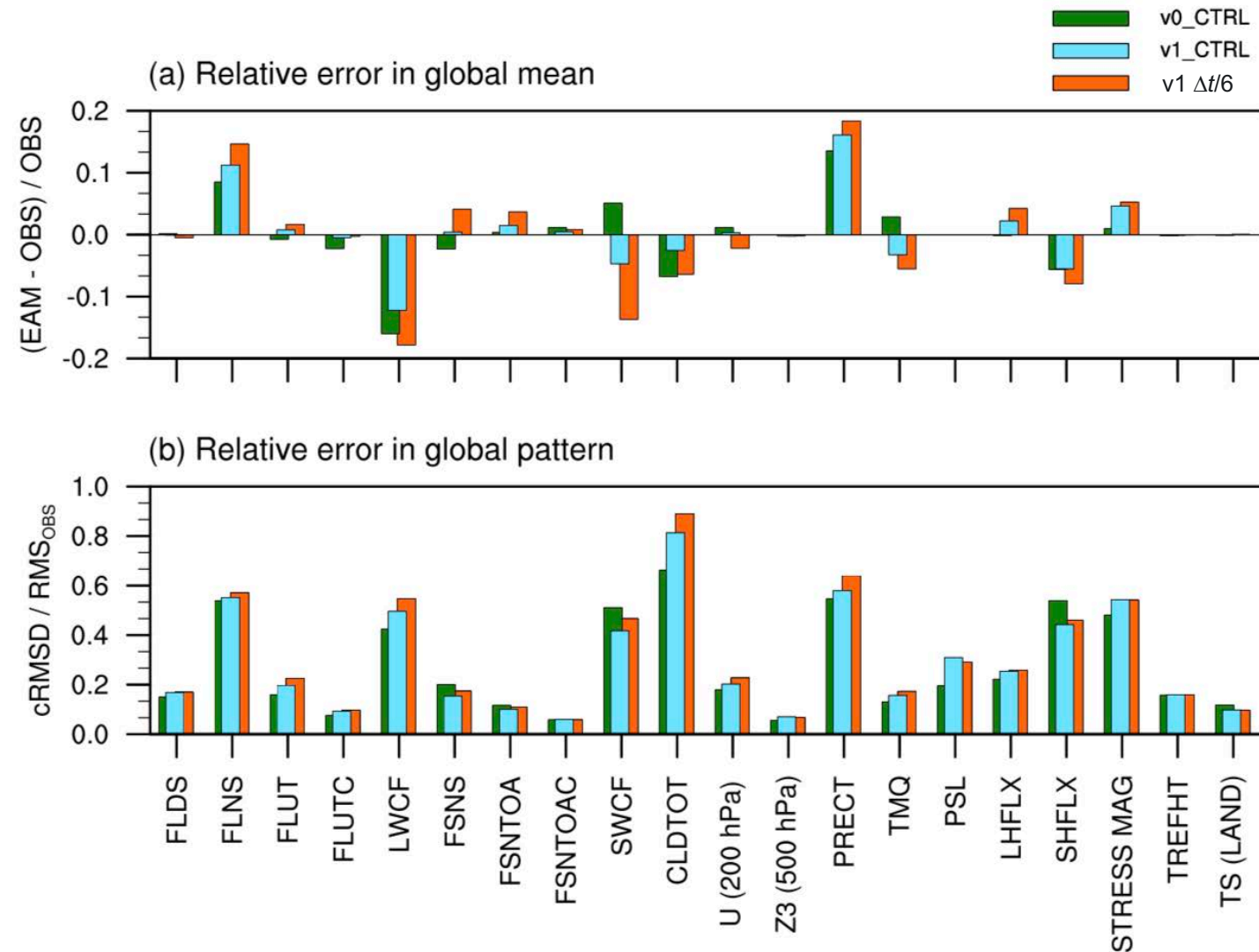
Simulation setup

- F_2000 compset
- ne30_ne30 (1-degree)

Source of obs. data:
AMWG diagnostics

The degradation in model fidelity is comparable in magnitude to the improvement from v0 to v1

Model biases in 10-year mean present-day climate



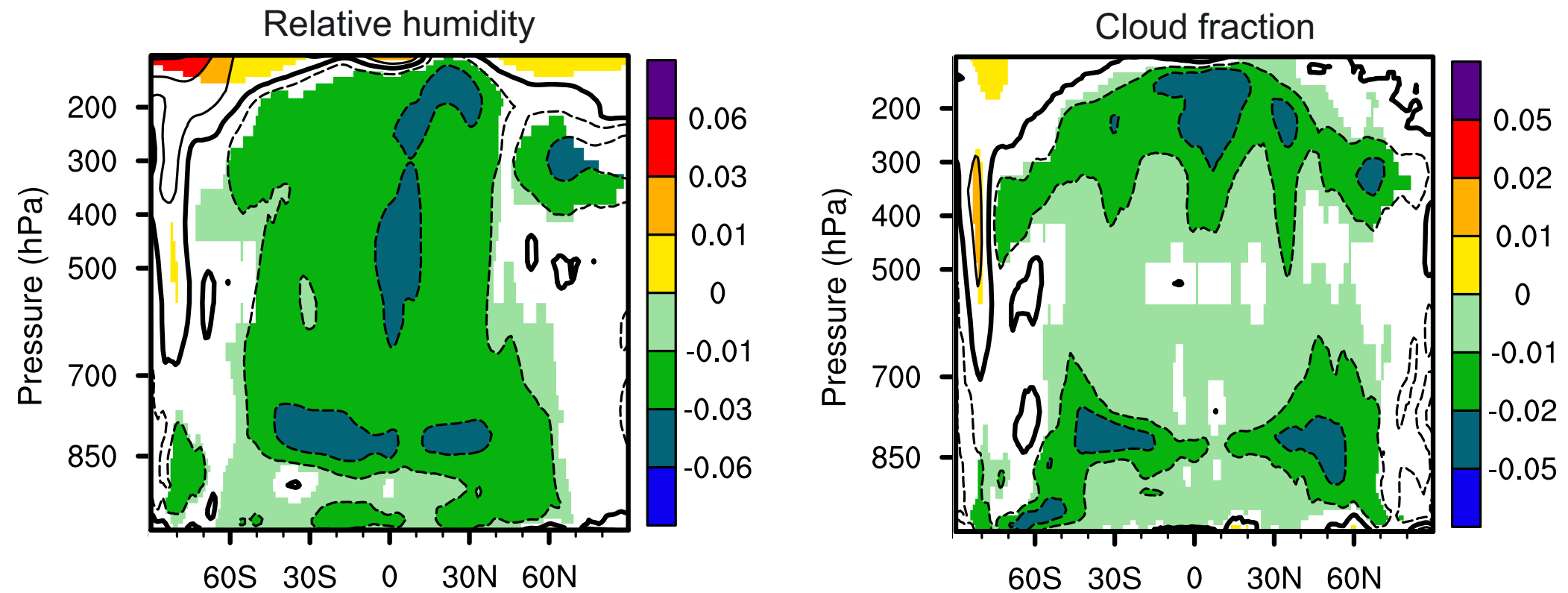
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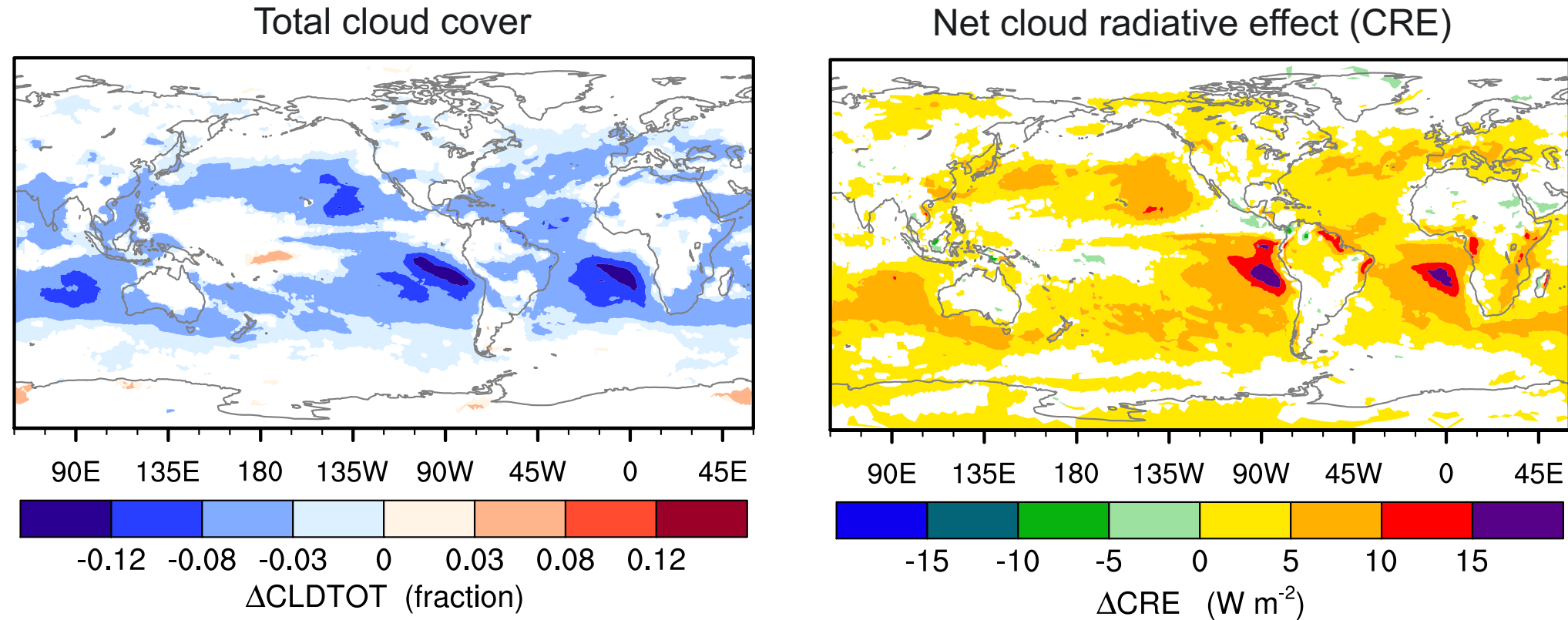
Key signatures of sensitivity include systematic drying of the troposphere and decreases in cloud fraction when time steps are shortened

Differences in zonal mean 10-year averages, $\Delta t/6 - v1_CTRL$



Significant changes are seen in subtropical low-clouds, which has potential implications on the prediction of climate change

Differences in 10-year averages, $\Delta t/6 - v1_CTRL$

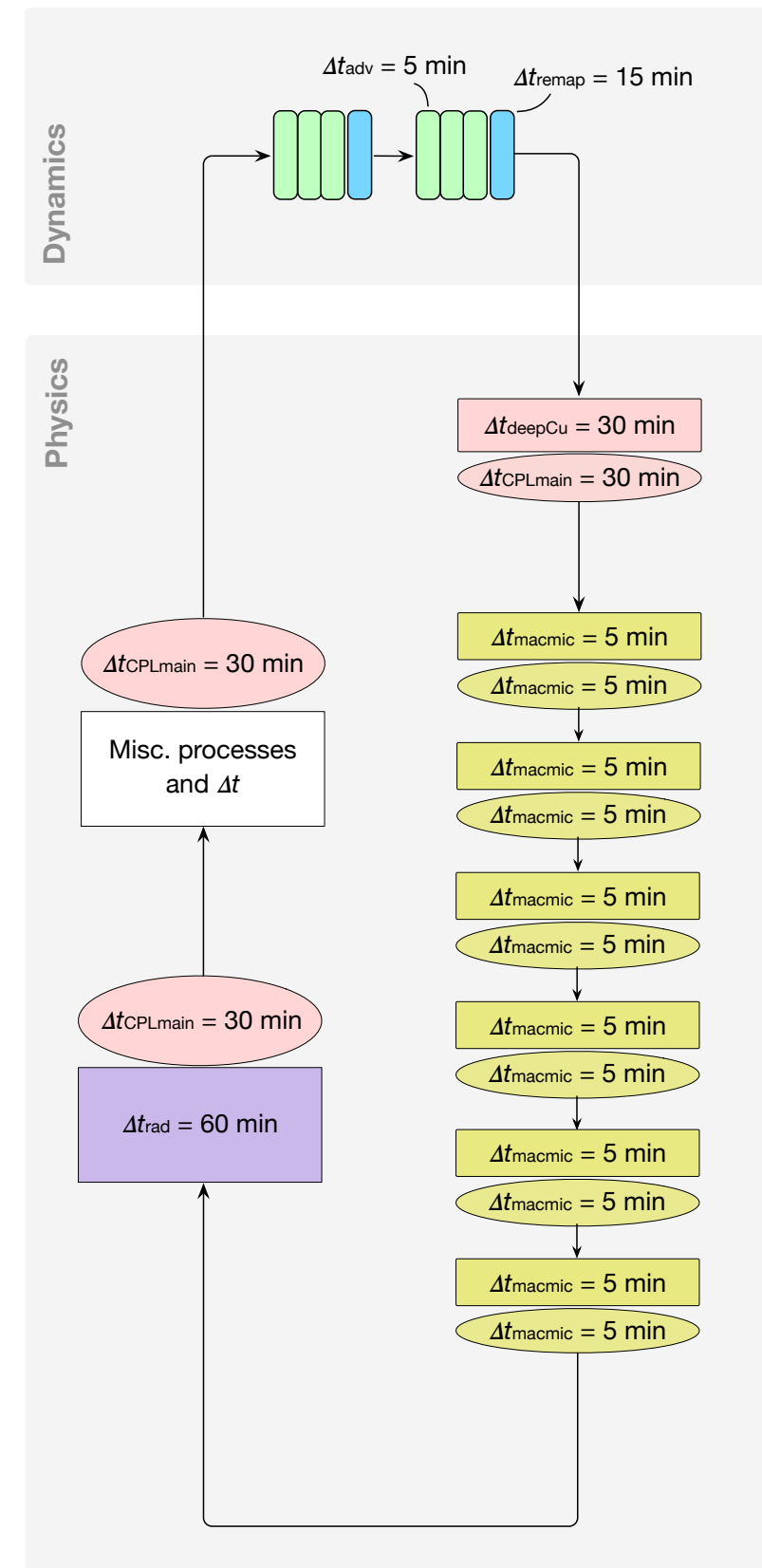


Wan et al. (2020, GMD Discussion, doi: 10.5194/gmd-2020-330)

“Perhaps unsurprisingly to those familiar with model development, the largest deviations can be attributed to the parametrizations of clouds and moist convection. **Perhaps less predictable is how and where these deviations are...**” — anonymous reviewer

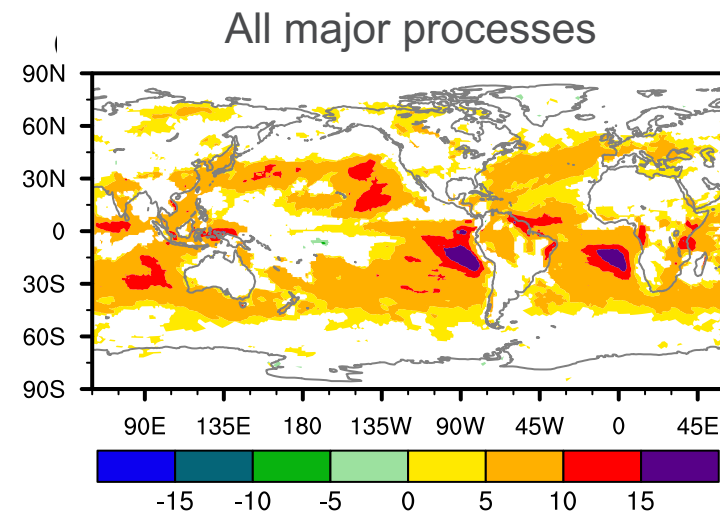
- “How and where”
- “By what and why”

Our experiments: time step sizes in various components of EAMv1 are varied separately or in combination to attribute time step sensitivities

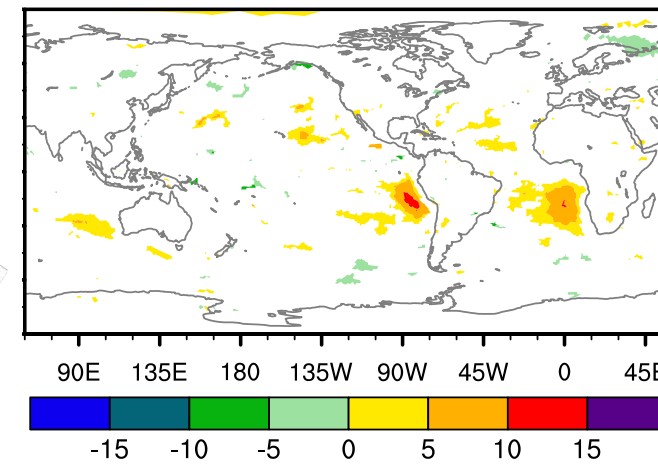


These simulations reveal key impactors in different cloud regimes

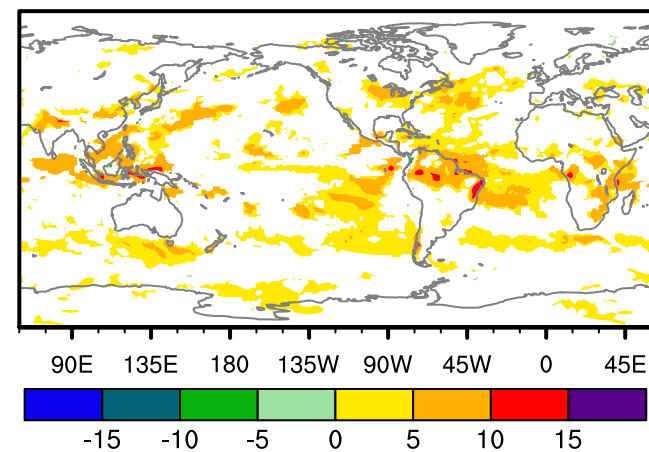
Differences in 10-year averages of **shortwave** cloud radiative effect



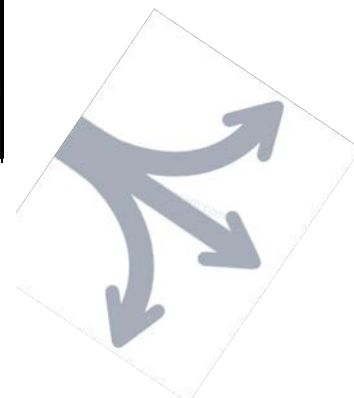
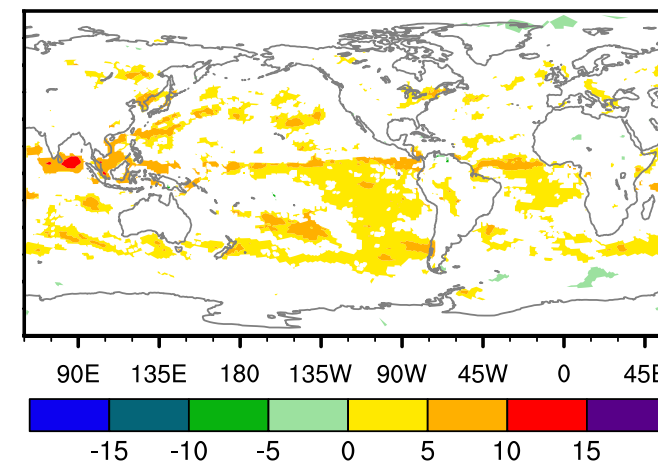
Coupling between cloud macro-/microphysics and rest of model



Shallow cumulus and stratiform cloud macro/microphysics

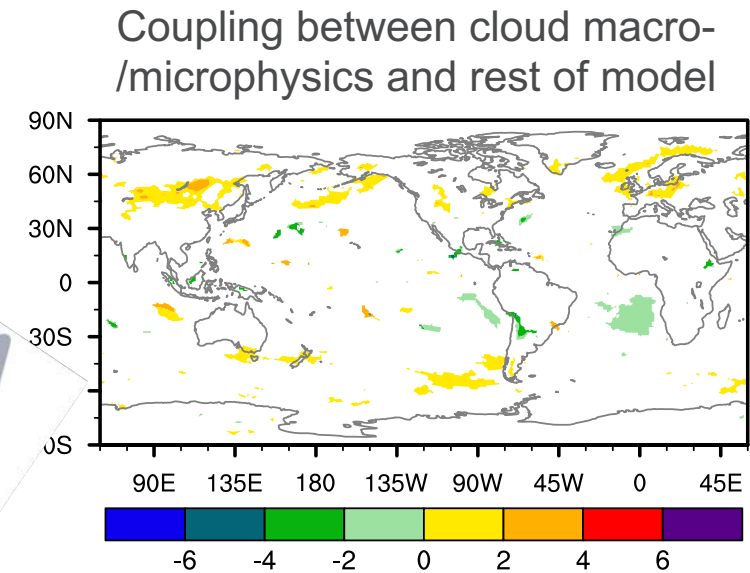
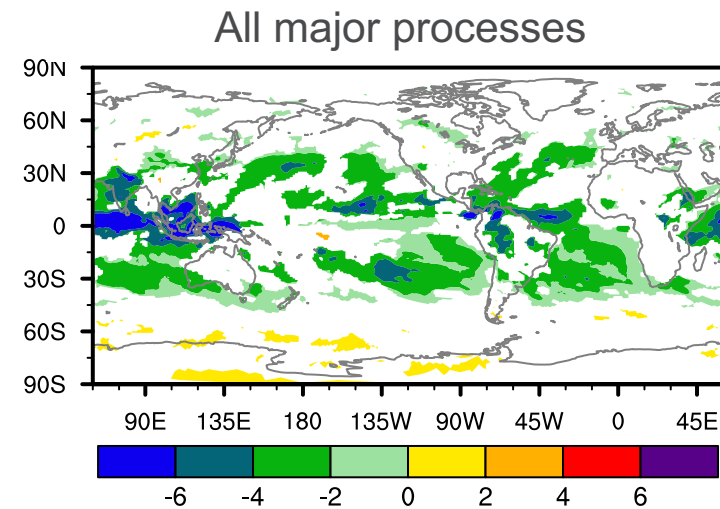


Deep convection and its interaction with dynamics etc.

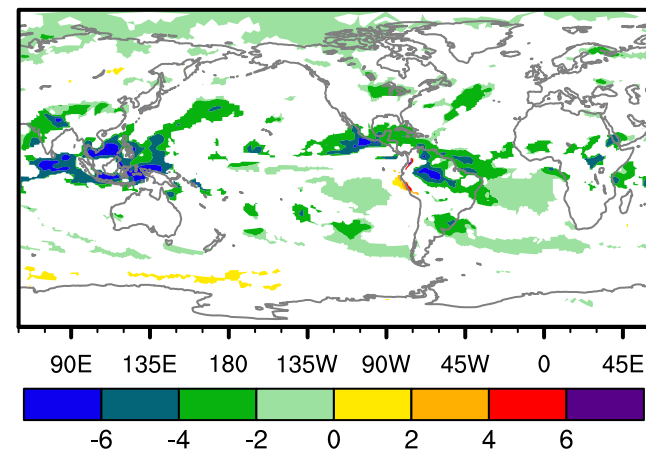


These simulations reveal key impactors in different cloud regimes (cont'd)

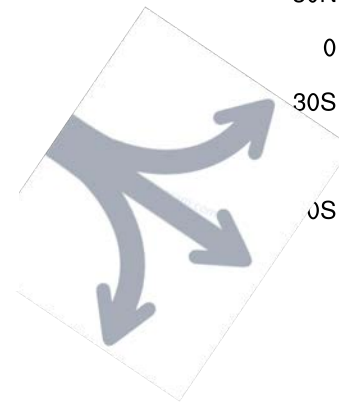
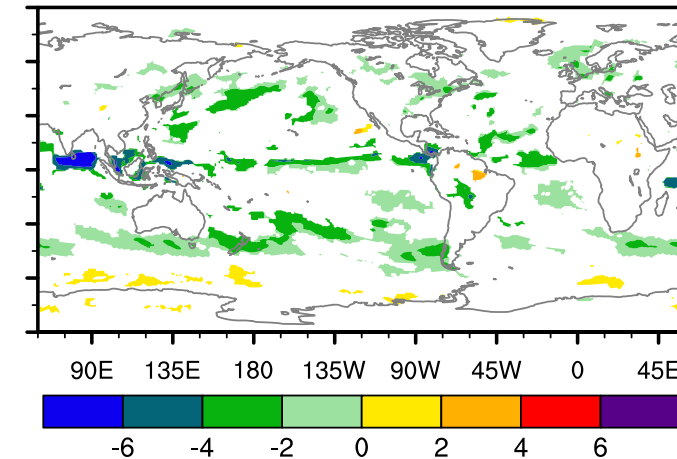
Differences in 10-year averages of **longwave** cloud radiative effect



Shallow cumulus and stratiform cloud macro/microphysics



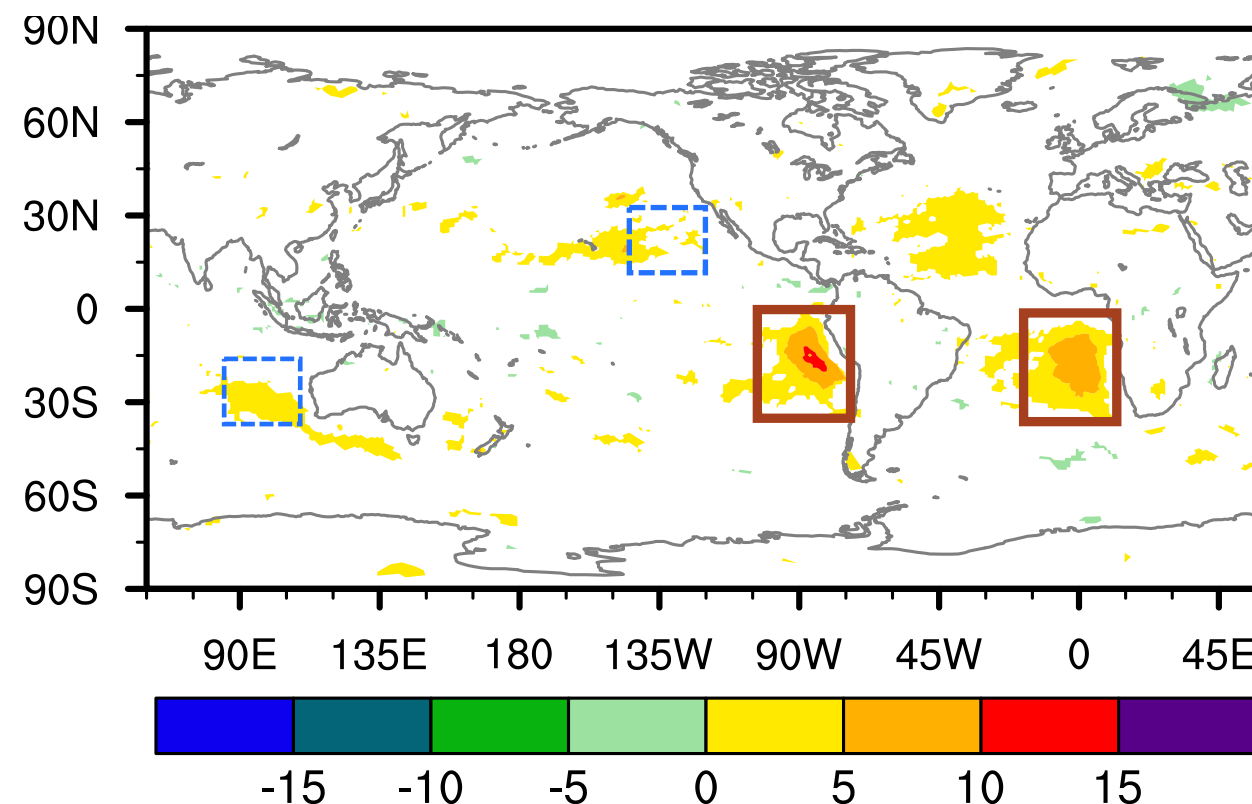
Deep convection and its interaction with dynamics etc.



Going beyond attribution — understanding and addressing the root causes

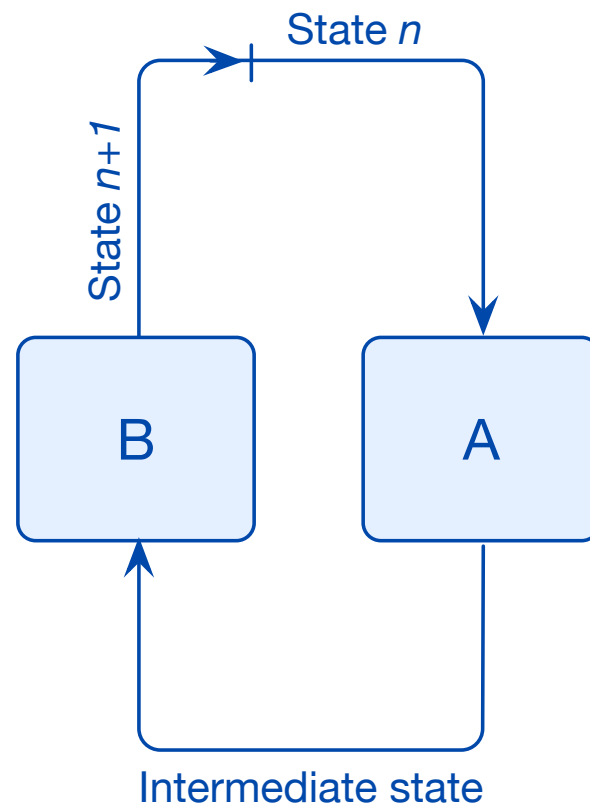
This presentation: discussing process coupling as an example

10-year mean total CRE differences caused by more frequent coupling between cloud macro/microphysics and rest of model

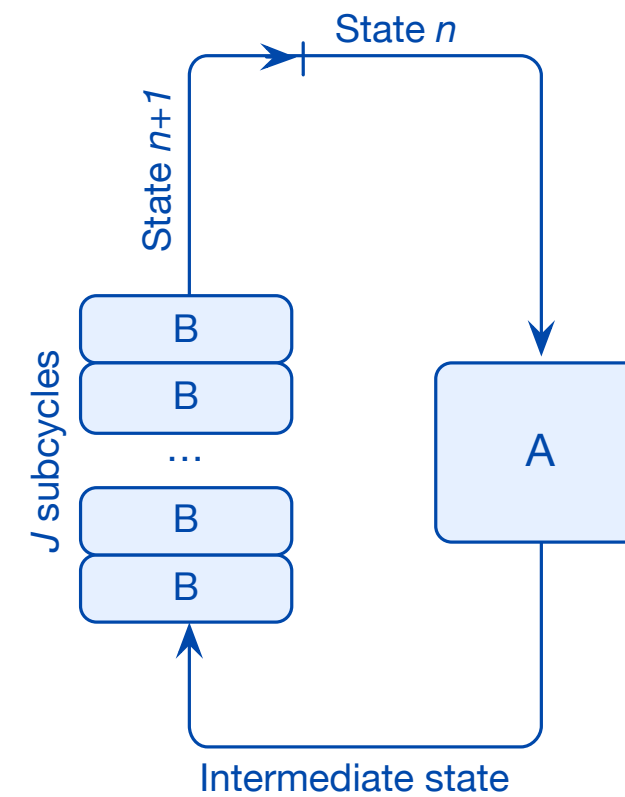


Sequential splitting is the primary process coupling method used in EAM

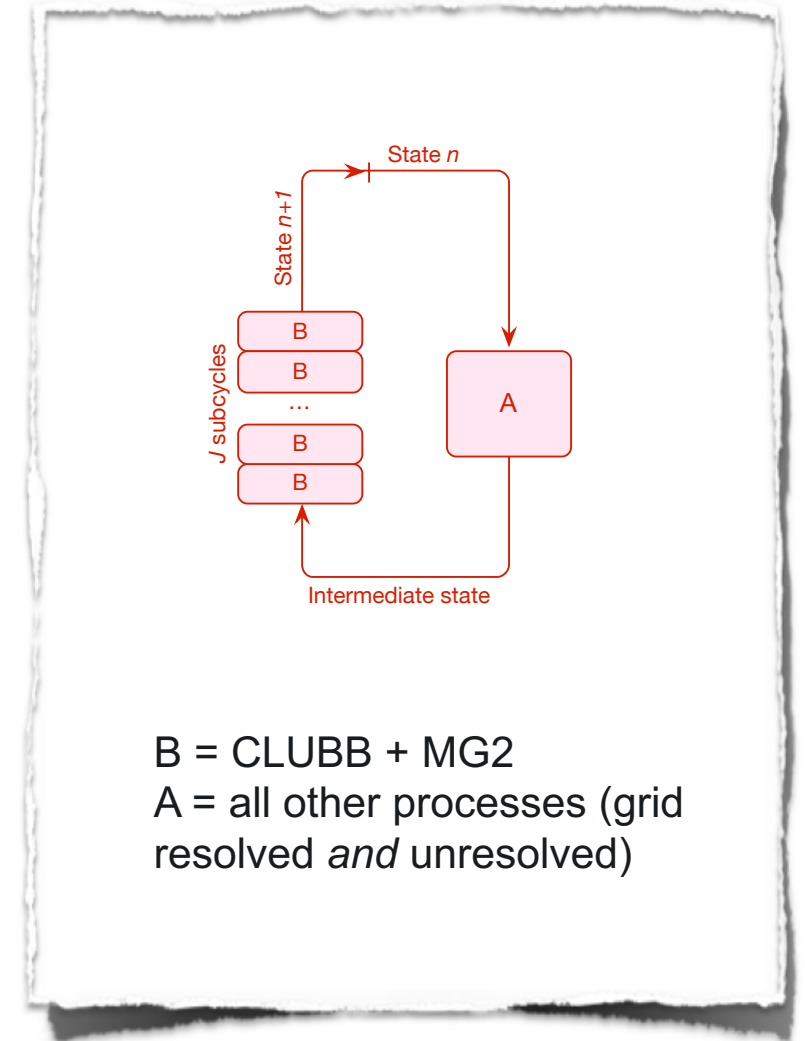
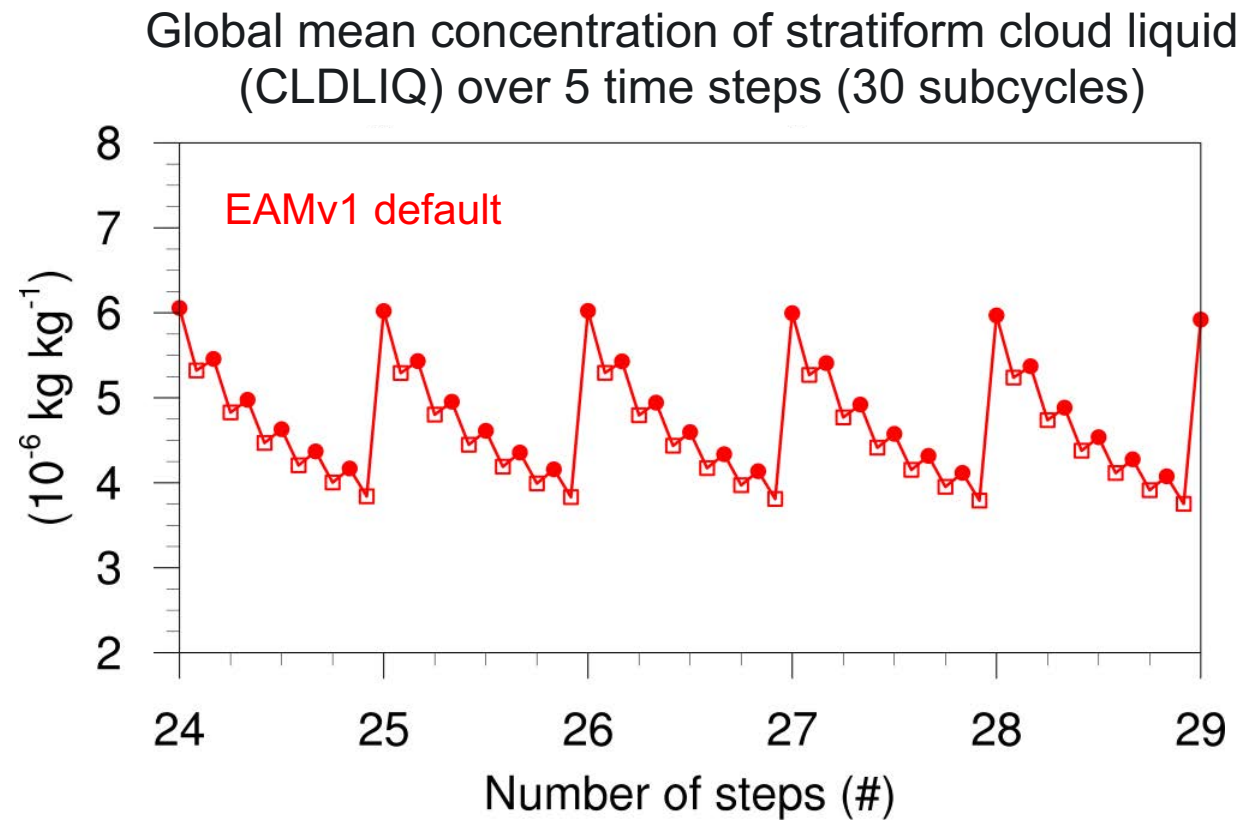
Without substepping



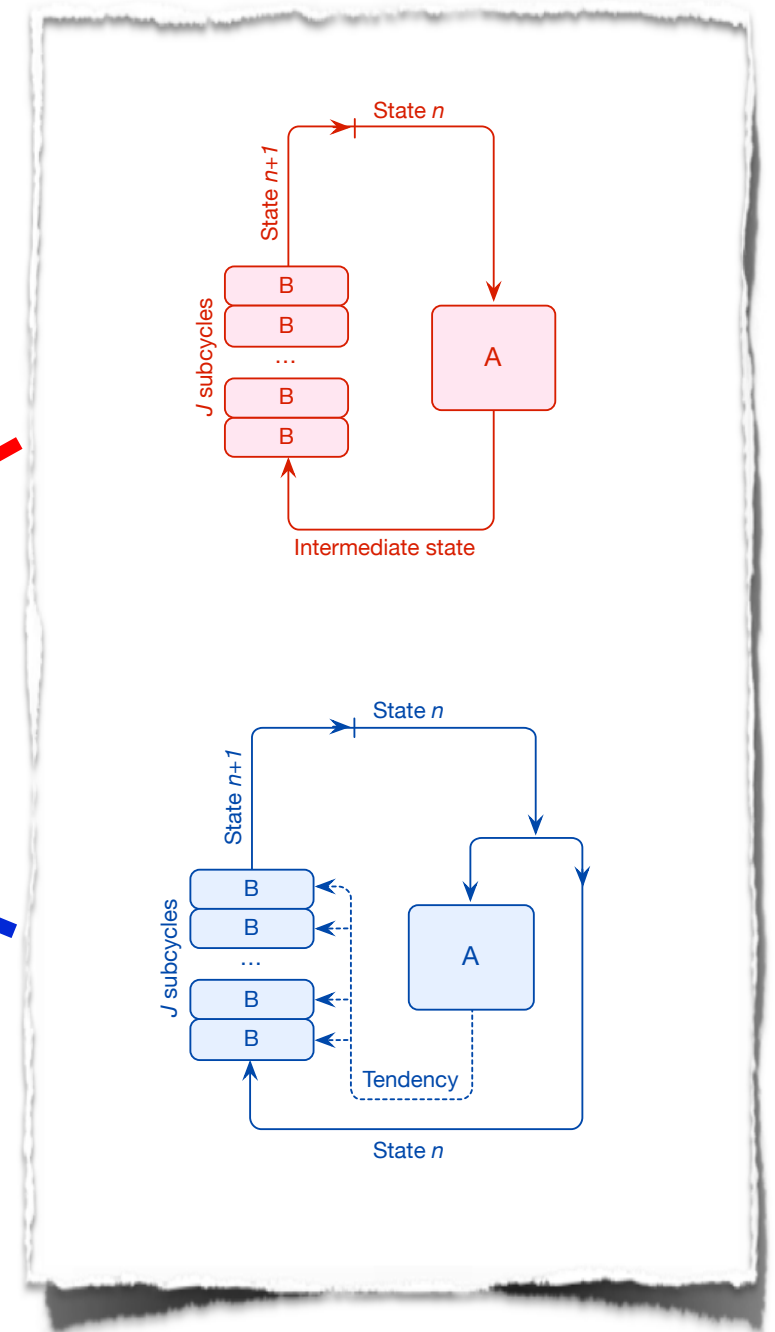
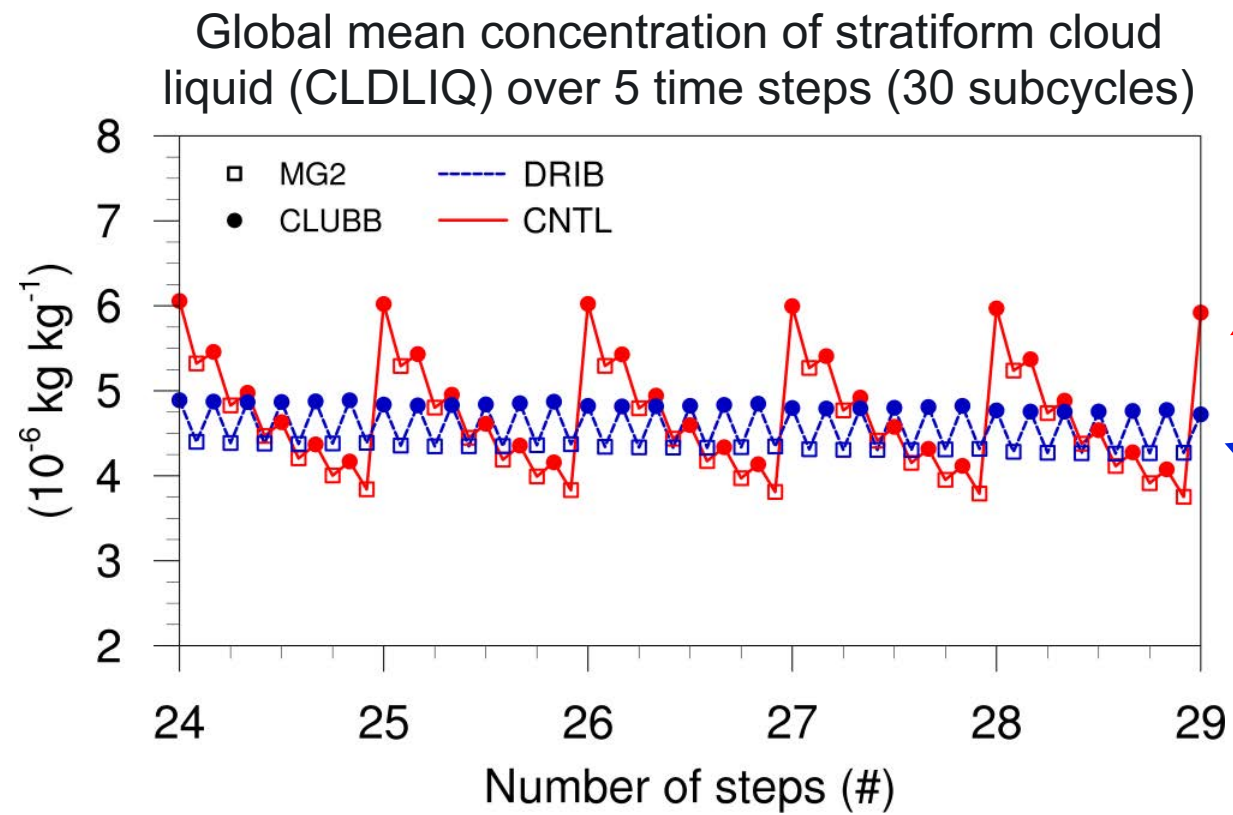
With substepping



Sequential splitting can cause strong oscillation of atmospheric state within each time step

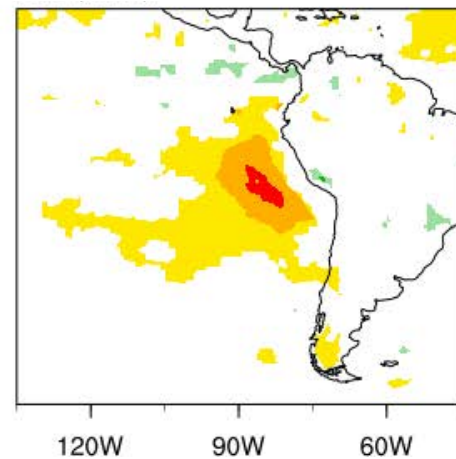


Tighter coupling can help alleviate the problem



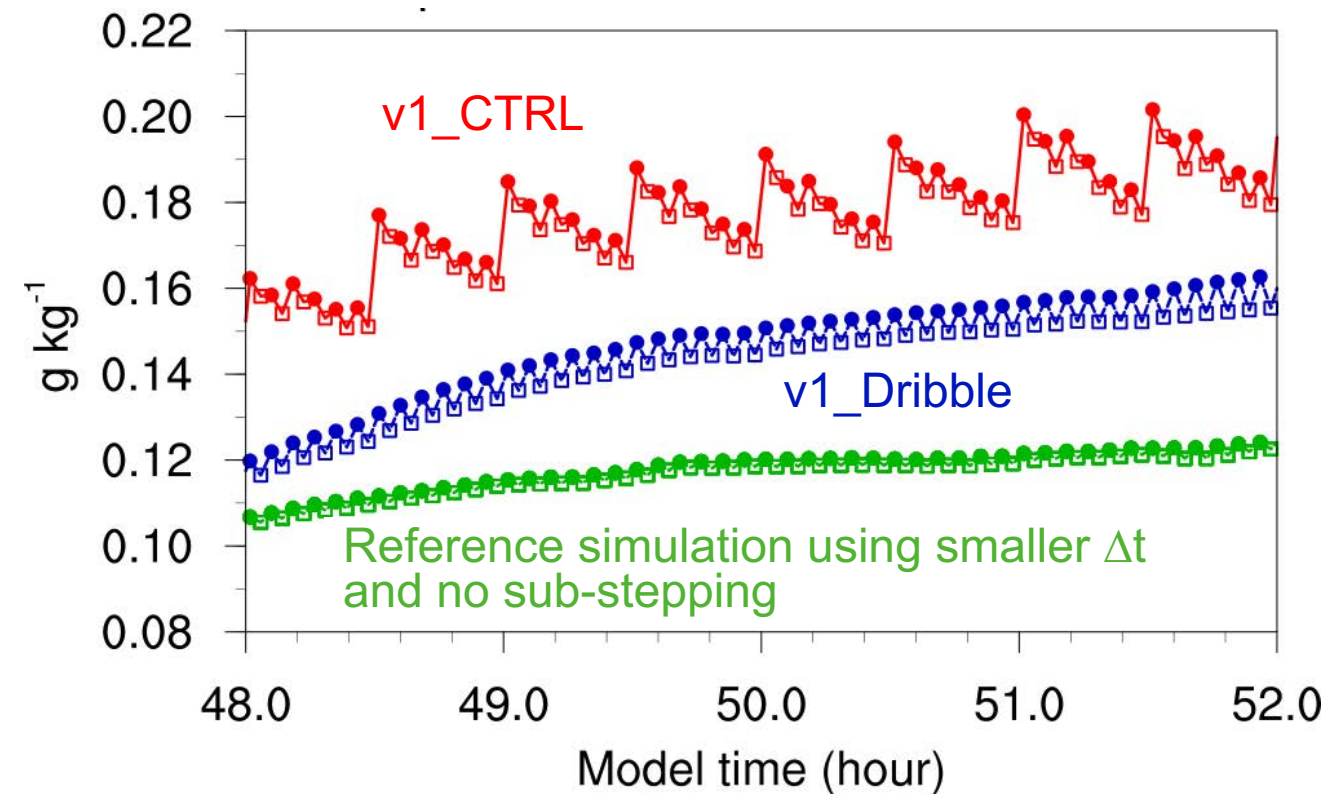
Change in coupling frequency can lead a shift of the mean state

ΔCRE , v1_Dribble – v1_CTRL



Why decreases in stratocumulus?

Peruvian stratocumulus region,
4-hour time series of CLDLIQ (700-1000 hPa)

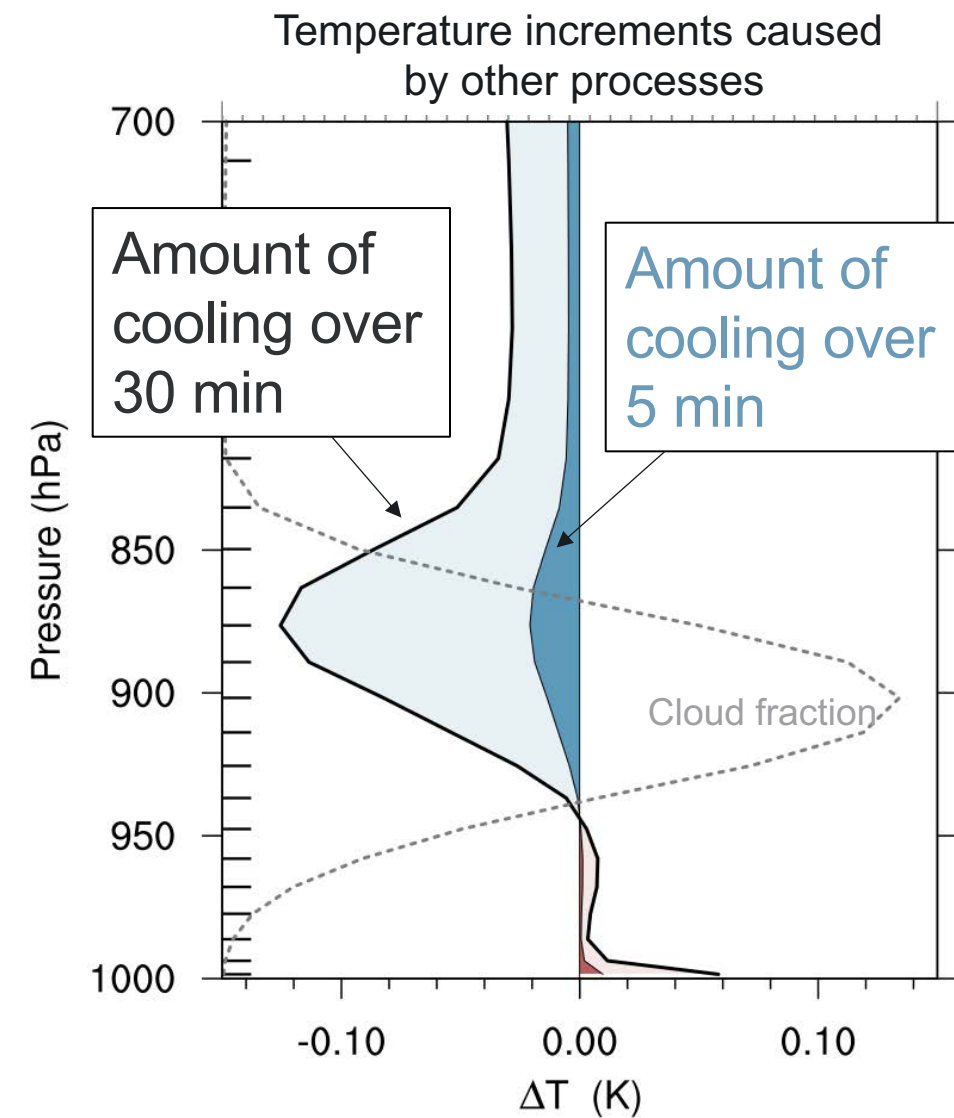


Sequential splitting results in a direct impact of coupling step size on the atmospheric state seen by CLUBB

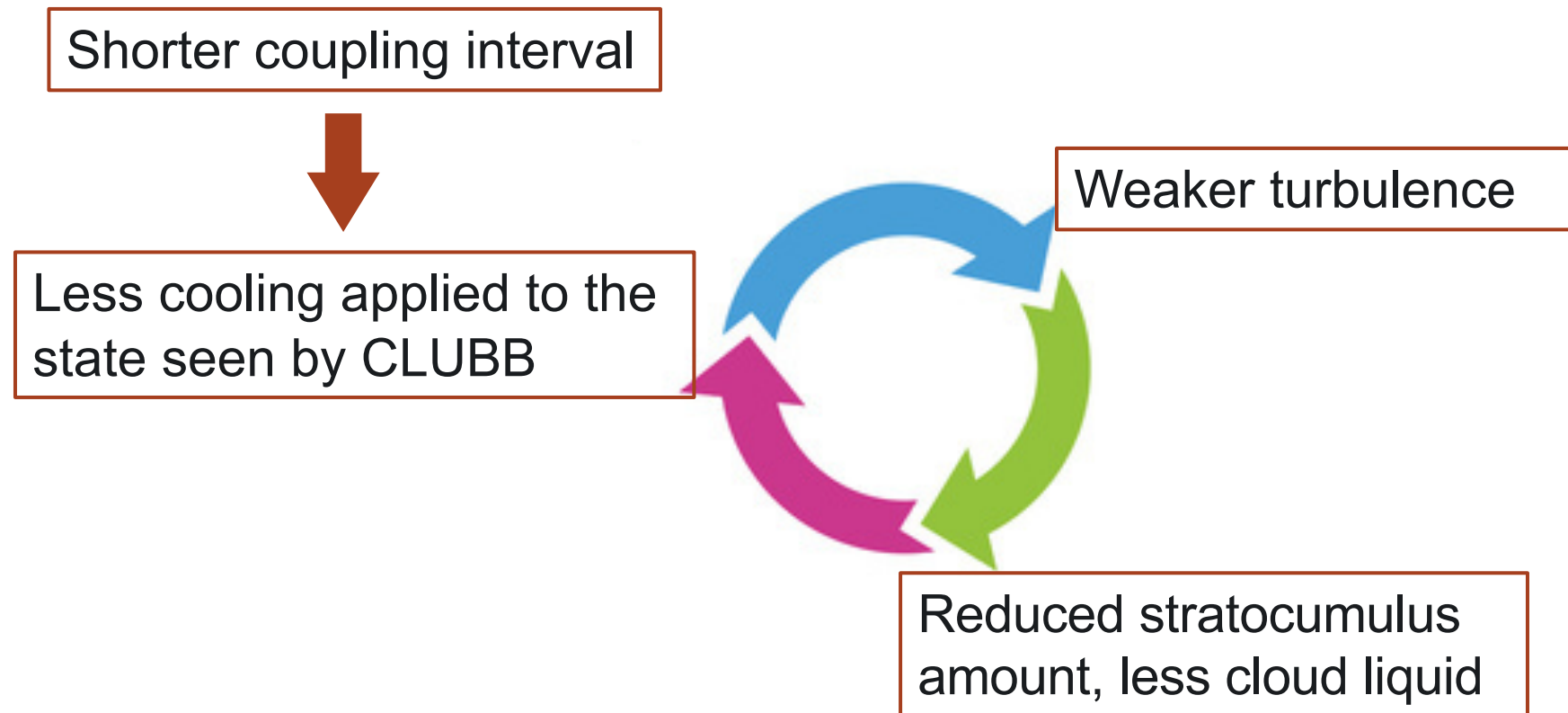
Shorter coupling interval



Less cooling applied to the state seen by CLUBB



Positive feedback between cloud-top cooling and stratocumulus amount enhances the model's response to coupling frequency

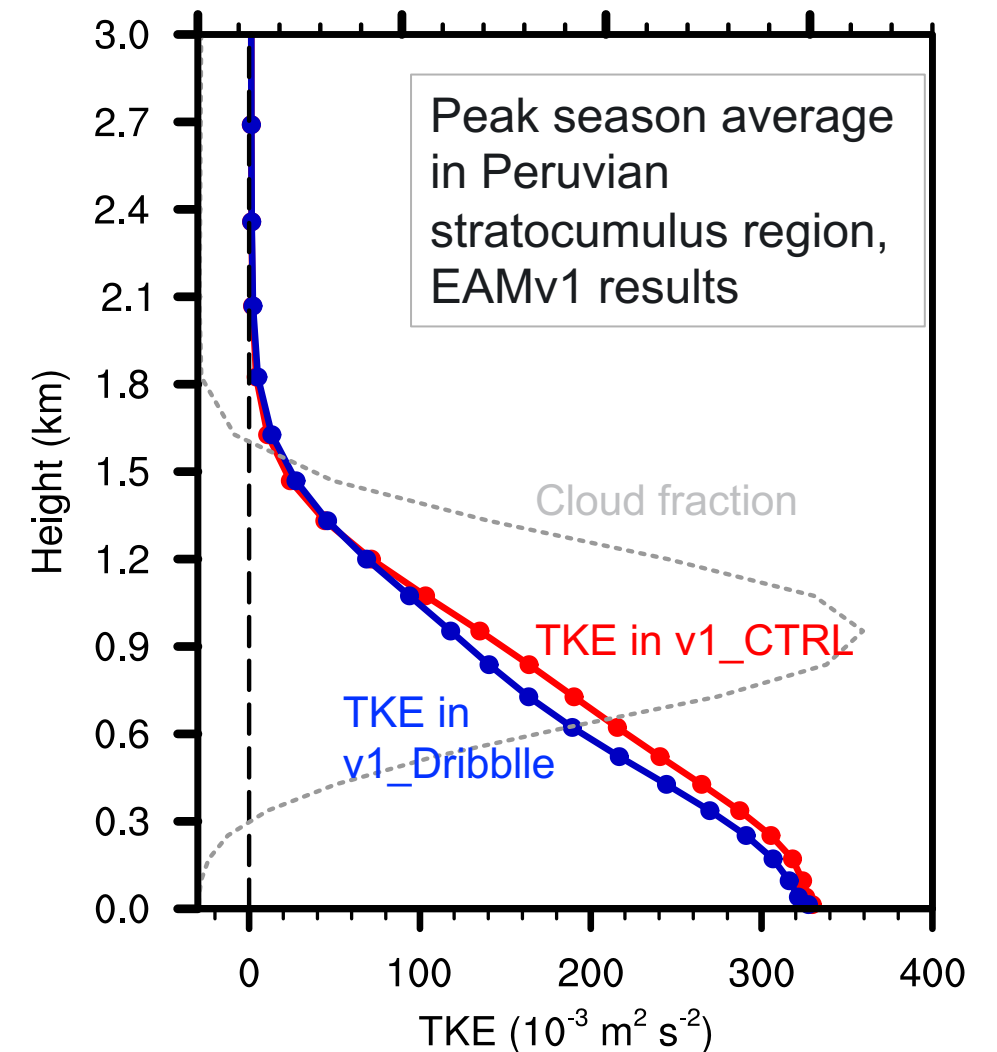


Diagnostics from inside CLUBB support our hypothesis

- Weaker turbulence and buoyancy flux in the boundary layer
- Decreased convective stability at cloud top

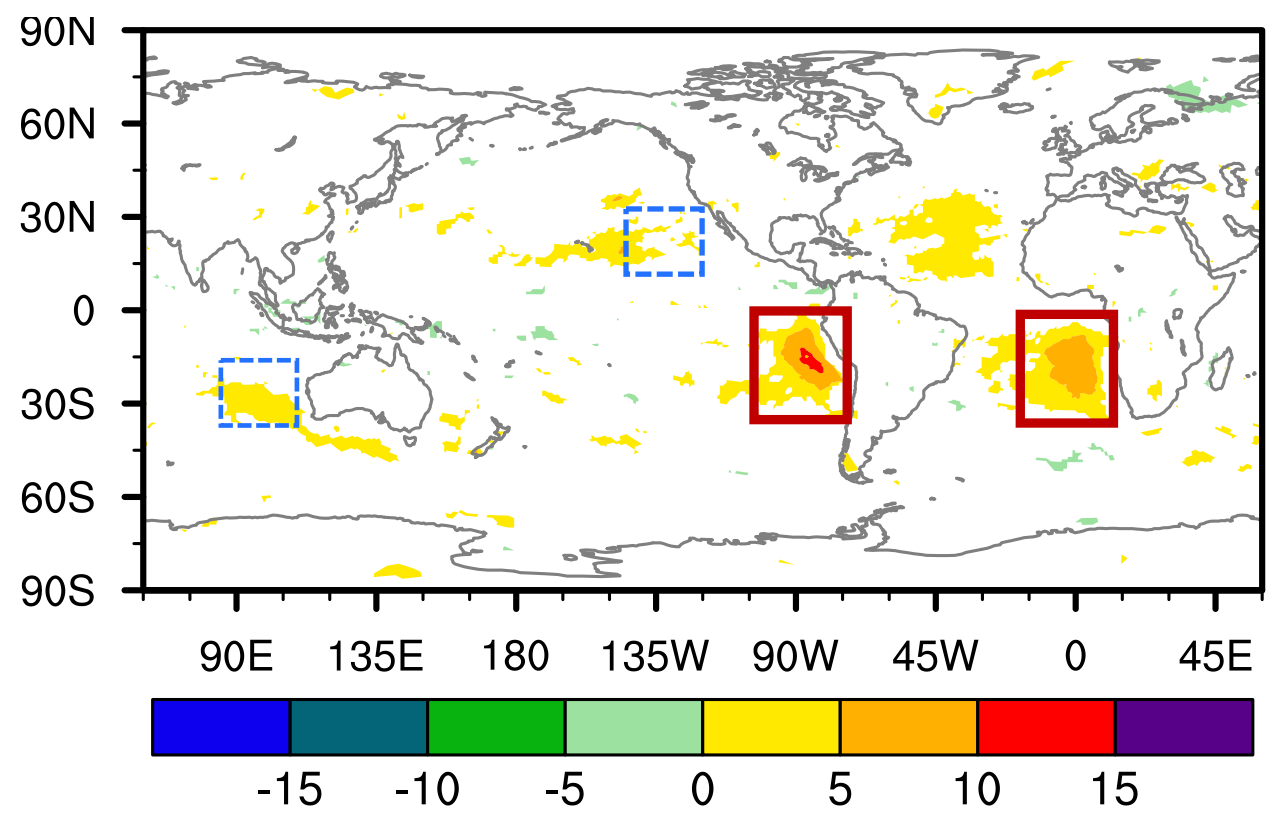
Single-column simulation further confirms the role of radiation

- DYCOMS-II RF01 case
- No deep convection
- No horizontal advection
- With or w/o microphysics, with or w/o shortwave radiation, model shows the same qualitative behavior

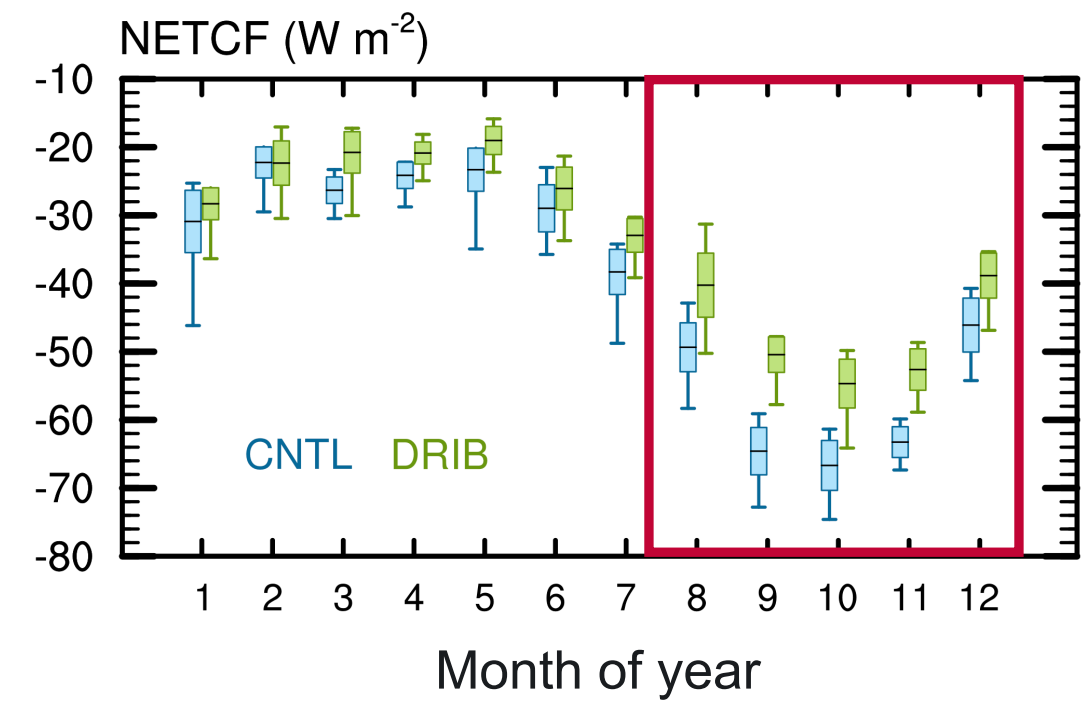


Impact of process coupling appear to be time and location dependent - why?

10-year mean Δ CRE caused by more frequent coupling between cloud macro/microphysics and rest of model

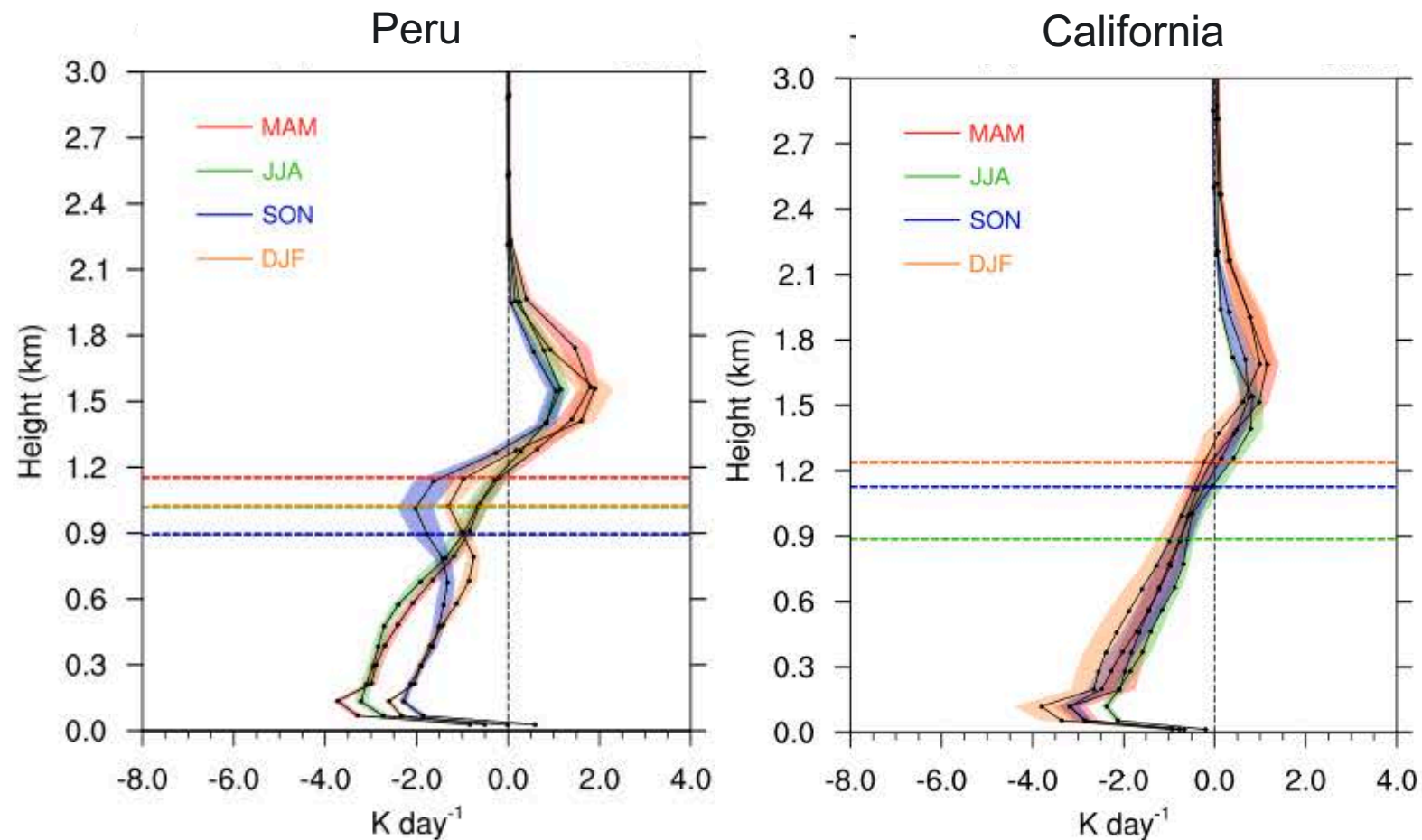


Annual cycle of CRE over the Peruvian stratocumulus region

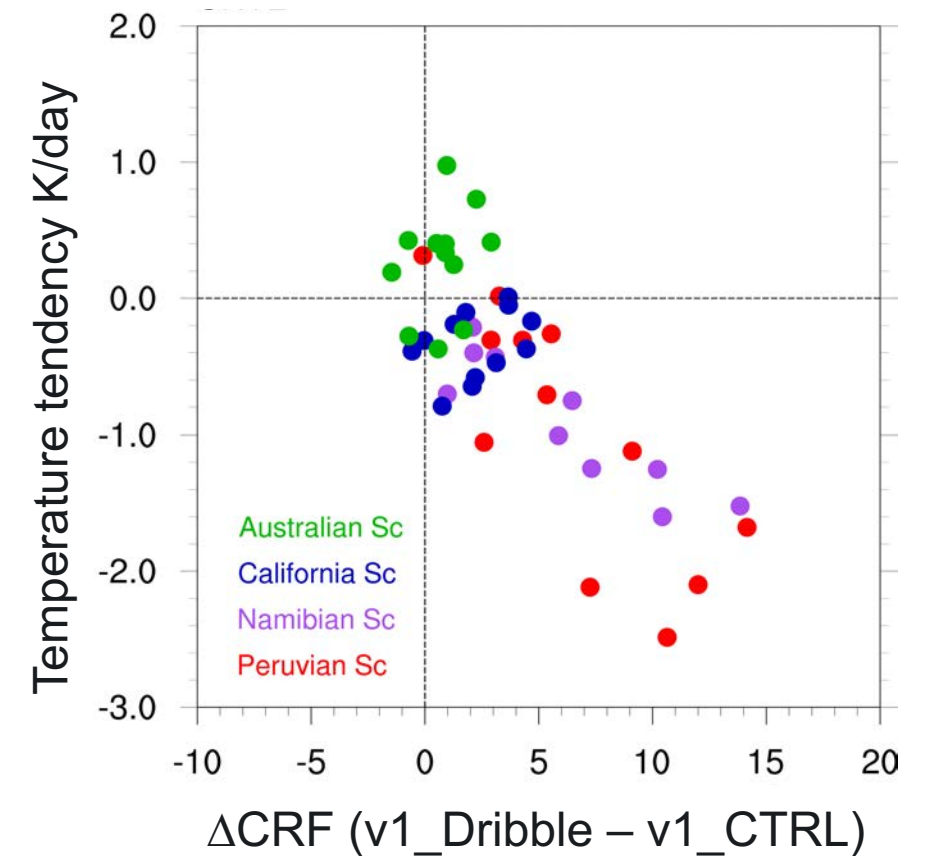


The proposed mechanism is expected to be valid only when radiative cooling is sufficiently strong to result in a negative out-of-subcycle T-tendency

Seasonal averages of out-of-subcycle T-tendency



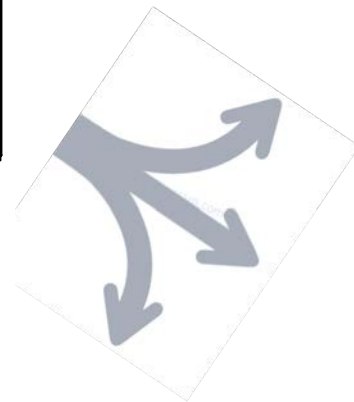
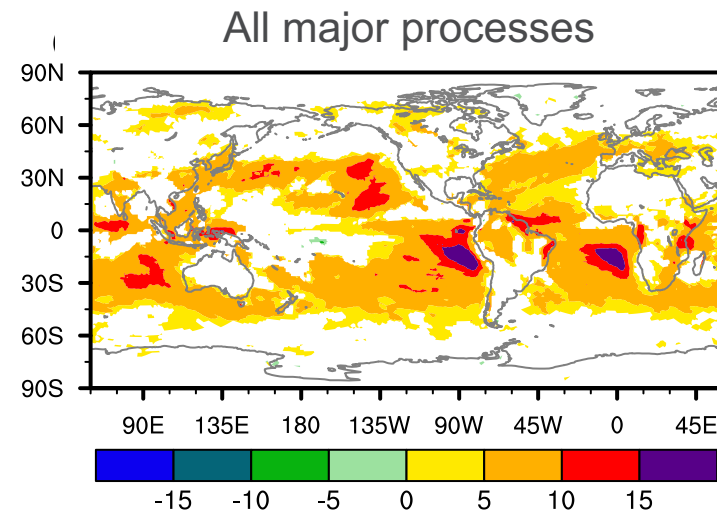
Monthly mean out-of-subcycle T-tendency v.s. Δ CRF



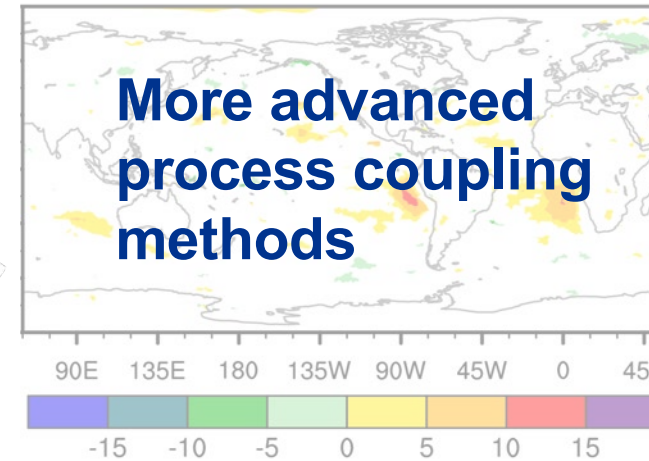
Conclusions so far

- Time step sensitivity is non-negligible in EAMv1's present-day climate simulations
 - Inconvenient for model developers focusing on model fidelity
 - Indication of significant time-stepping error needing to be addressed
- Sources and root causes of time step sensitivity can be identified and addressed
- Process coupling is an important area to put more efforts in

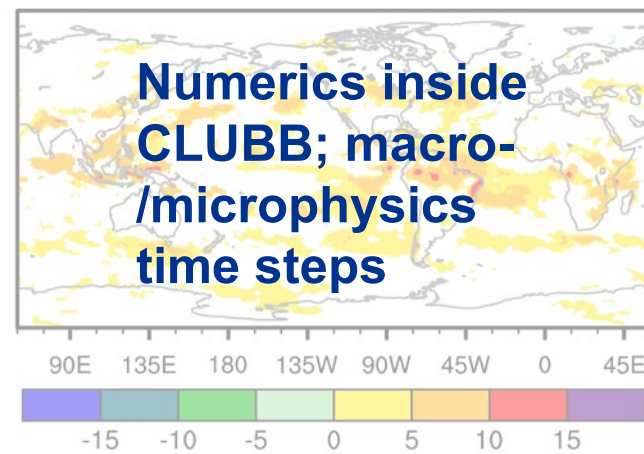
On-going and future work



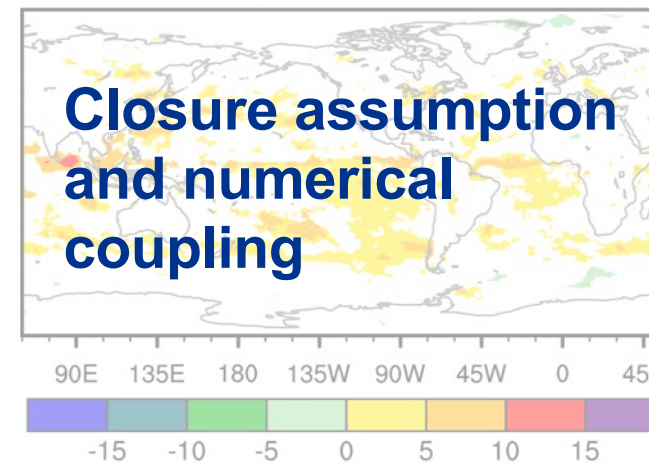
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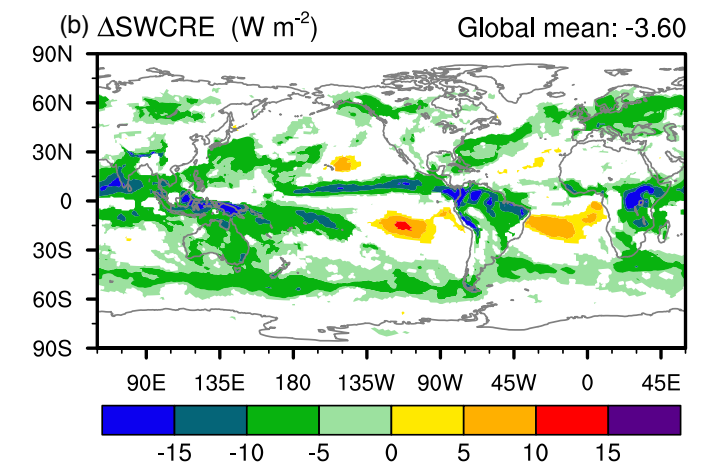
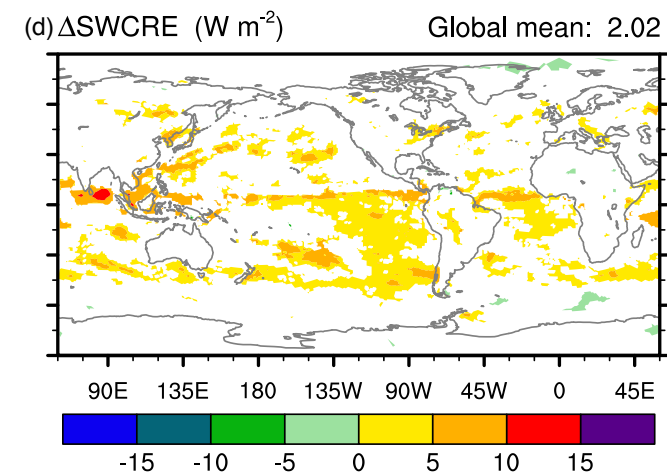
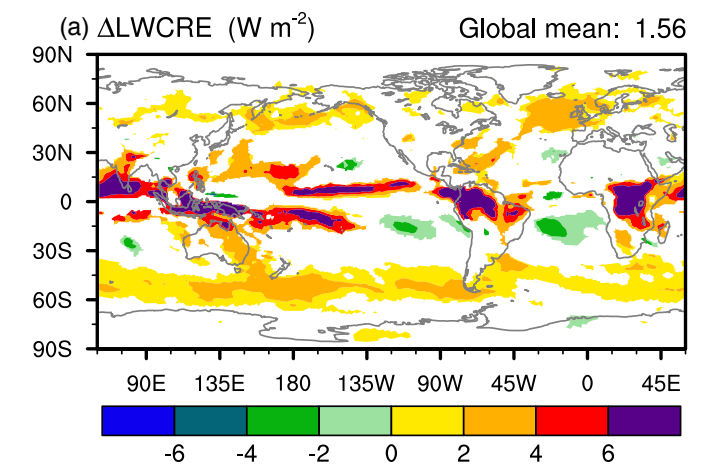
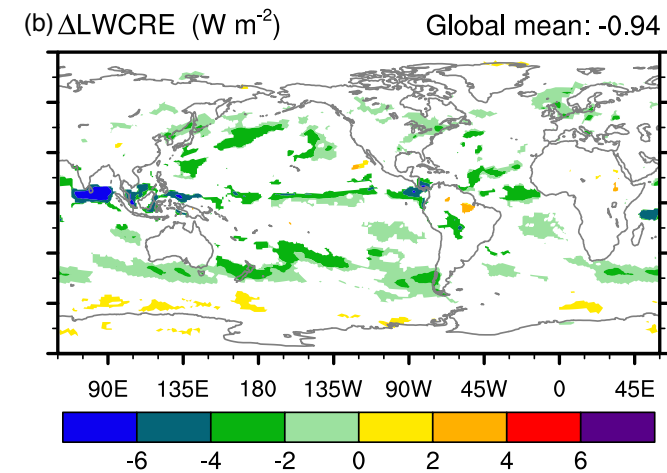


Teaser slide: deep convection, time steps, and timescales

10-year annual mean ΔCRE corresponding to a factor-of-6 reduction of $\Delta t/\tau$

by changing Δt

by changing τ



Can the $\Delta t/\tau$ ratio explain our observed time step sensitivities? Yes, but there is more to it.