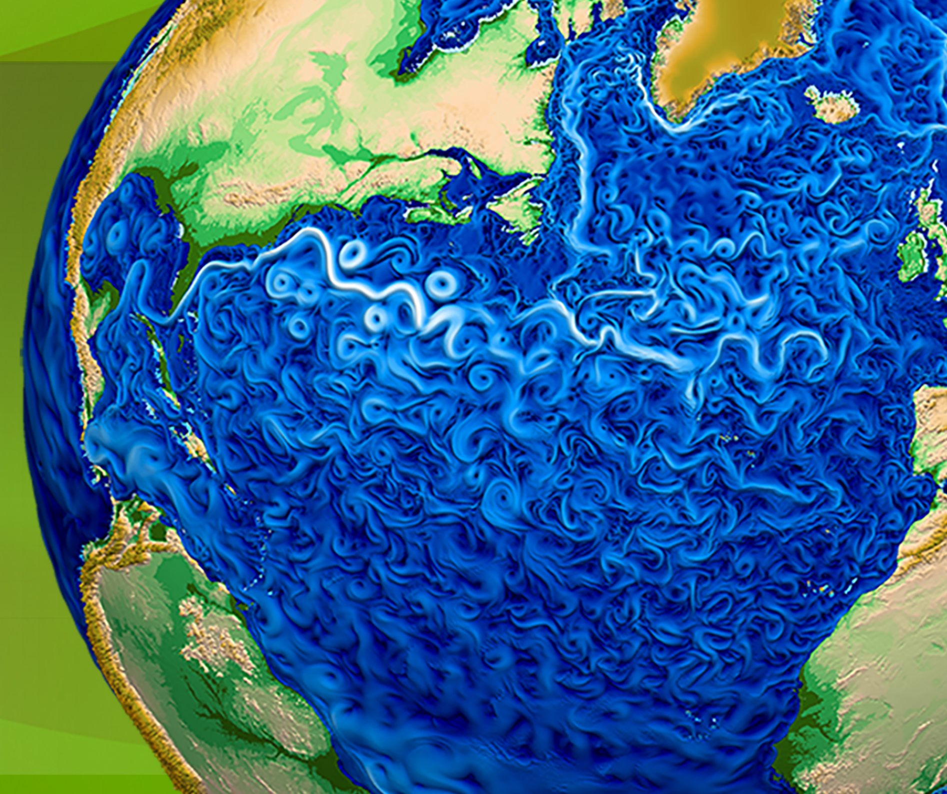
R: Impact of physics parameterization ordering in a global atmosphere model



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Objective

Atmospheric physics parameterizations in the ACME model are sequential-split in time as shown in Figure 1 (left side), this approach is not commutative and thus changing the order of splitting can potentially change the solution. The goal of this study is to assess the impact of changing process order.

Approach

Focusing on the processes in the 'before coupling' section of the code:

- Deep Convection (DC)
- Shallow Convection (SC)
- Macrophysics (Ma)
- Microphysics & Aerosols (Mi)
- Radiation (Ra)

The full set of 5! = 120 possible orderings of these 5 processes were run for 1 year.

The simulations were then organized into groups with similar results using K-mean clustering, see Figure 1 (right side)

ACME Diagram and set of study simulations

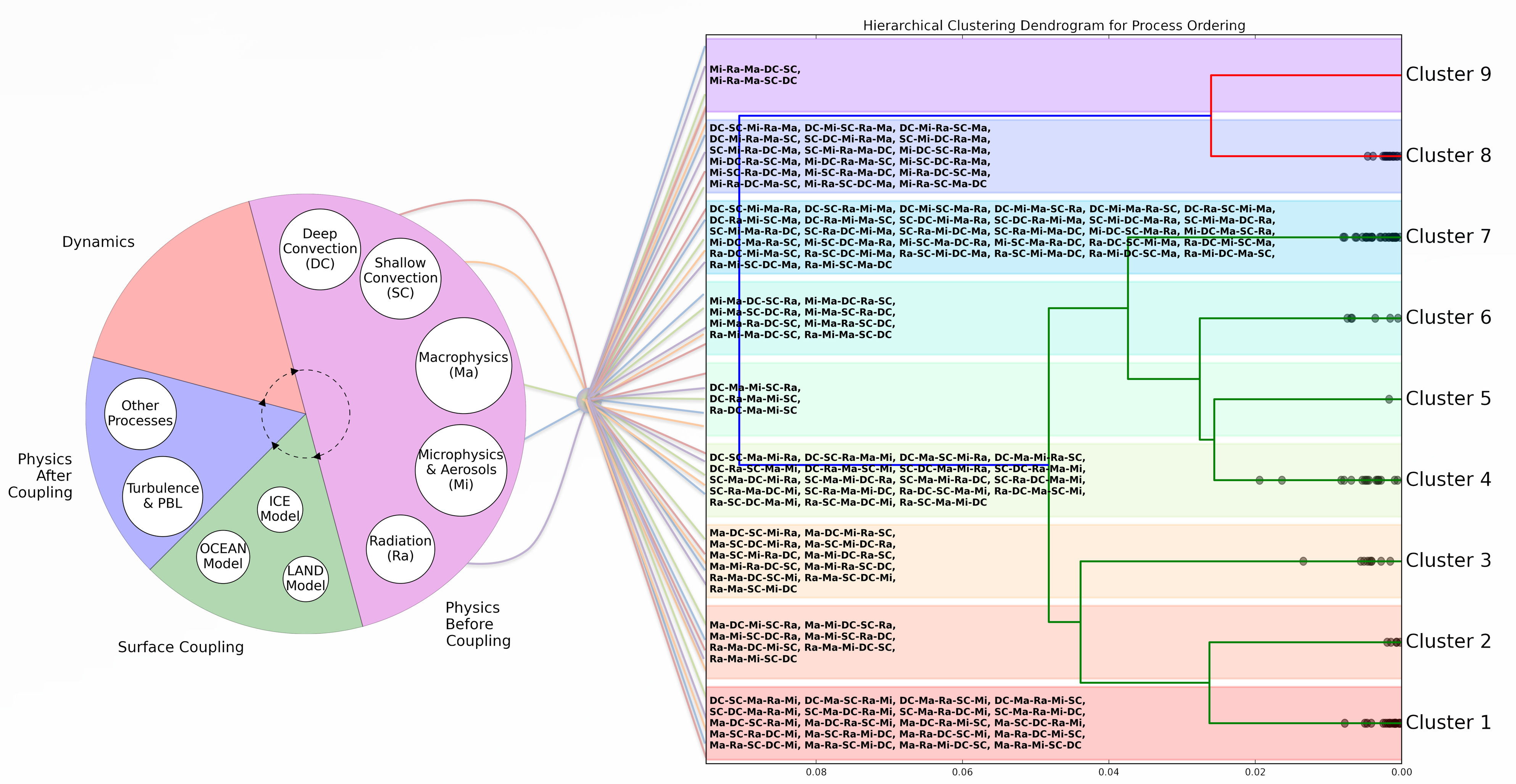

Figure 1: Model setup for study. Left side: diagram of sequential-split components of the atmospheric model in ACME. Processes of interest are listed with a two-letter key which is used for sequence labeling. Right side: dendrogram of processes with similar solution properties. Each process ordering member of a cluster is listed to the left of the dendrogram using the two-letter key.

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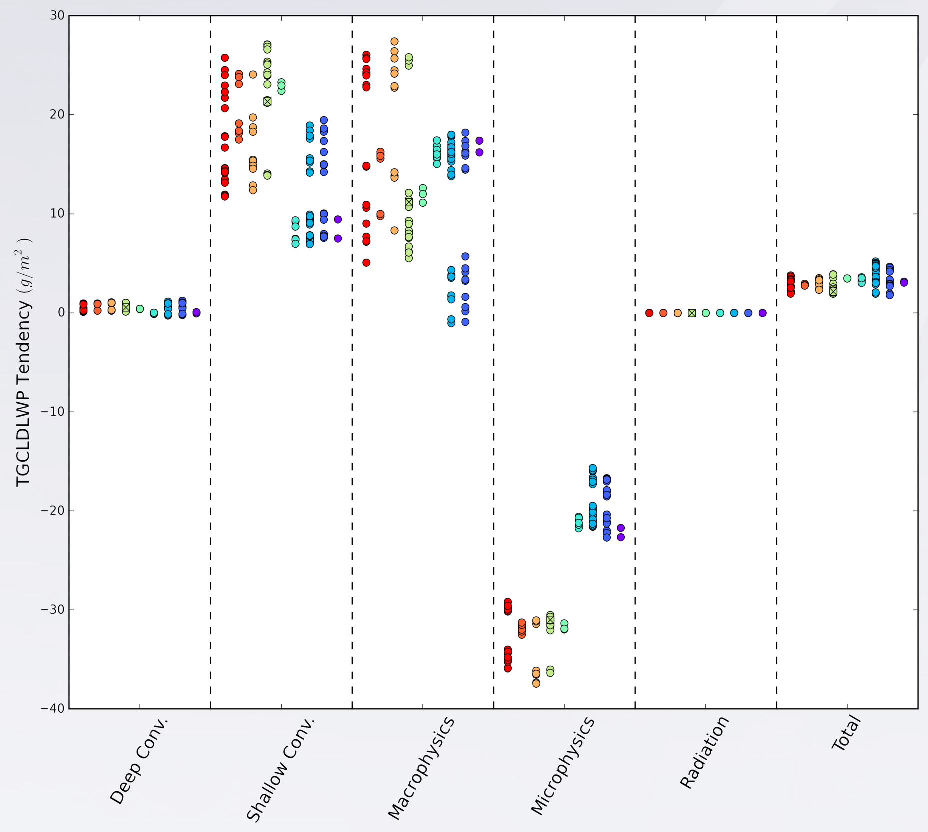
See ***Donahue A.S. and Caldwell P.M. "Impact of physics parameterization ordering in a global atmosphere model", JAMES (2017), submitted*** for more information

Explanation for Sensitivity

Changing process order affects output in 2 ways:

1. the model solution is different after each process within a timestep, see Figure 2. As a result, the location where output is written has a big impact on our understanding of the model solution.
   - This is important for model evaluation because model diagnostics and inter-model comparisons assume the model output represents the model state for the whole timestep, which is not accurate.
2. the effect of each process depends on the state it acts on. Since the input state is very different depending on which processes came before, order has a big effect on the tendency of each process. This is illustrated in Figure 3, which shows the global-average tendency for each process for each of the 120 simulations.

Fig. 3: Global average liquid water path (LWP) tendencies of each process for each of the 120 simulations in this study. Colors and offset correspond to cluster grouping (see Figure 1)



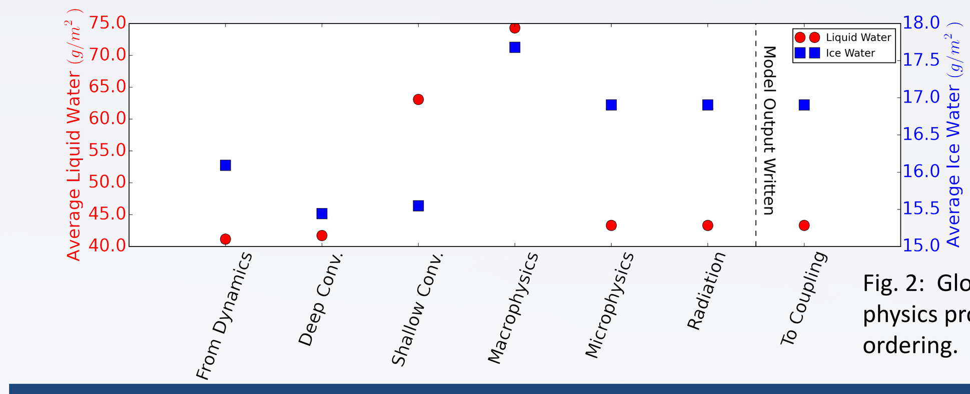


Fig. 2: Global average liquid water path (LWP) and ice water path (IWP), following each physics process in the before coupling component of the ACME model for the default ordering.

Impact

Impact on model skill:

Changing process order has a significant impact on the solution accuracy. Figure 4 shows the root mean squared error (RMSE) normalized by the standard model RMSE for all 120 simulations. In some cases the error can more than double, in other cases we can accomplish upwards of 20-30% improvement.

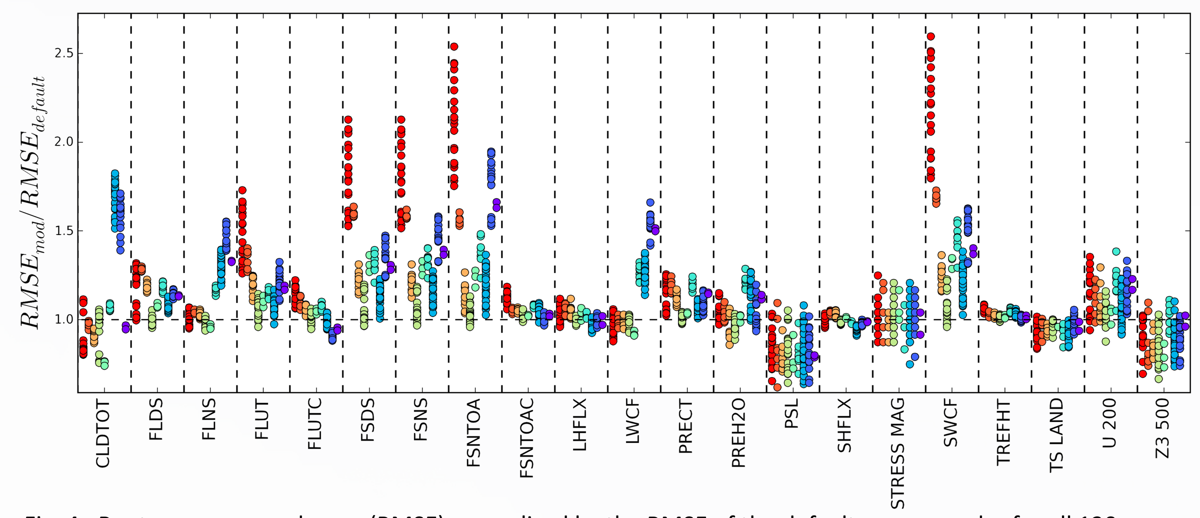
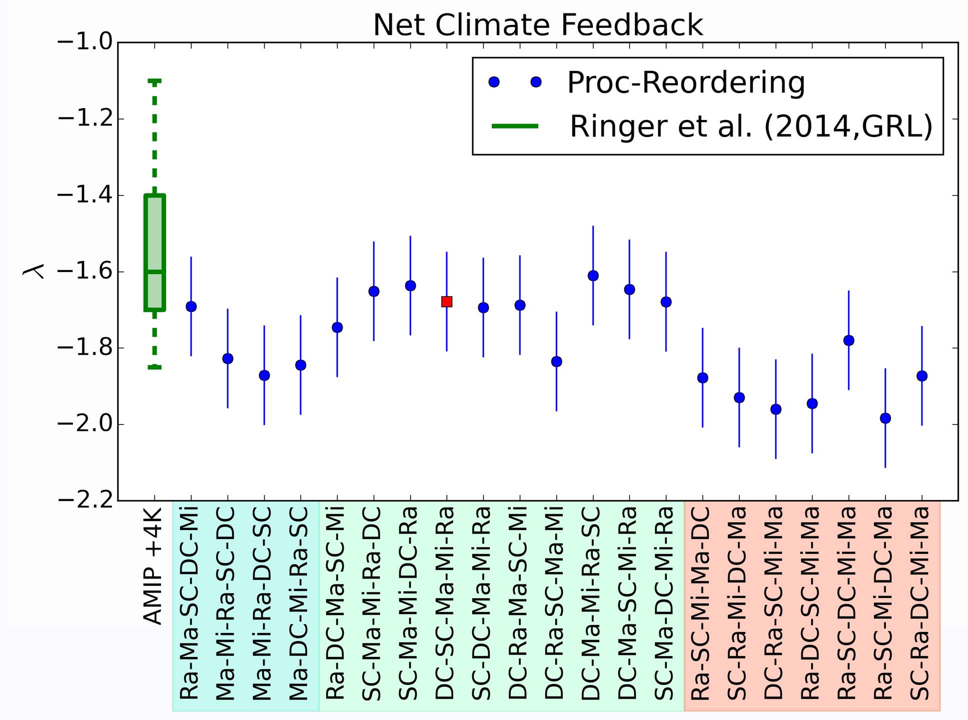


Fig. 4: Root mean squared error (RMSE) normalized by the RMSE of the default process order for all 120 simulations. Colors and offset determined by cluster membership, see Figure 1.

Impact on model predictions:



A subset of 21 runs with residual top of the model (RESTOM) radiation imbalance between -1 and +2 show that changing the process order can also significantly impact the net climate feedback, λ. Comparison with the values reported by Ringer *et al.* (2014 GRL) show that the variability in λ associated with changing process order accounts for roughly 50% of the variability in λ observed in the AMIP results.

Fig. 5: Net climate feedback values for 21 process orderings. Error bars represent 2 standard deviations of 10 years of simulations using the default order. X-label colors determined by cluster membership, see Figure 1. Default order shown with red square.

ACME Accelerated Climate Modeling for Energy

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