Impact of Physics Parameterization Order in the EAM v0 Model

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Deep Dark Secrets of Climate Models

Conclusions:

1. Each process acts upon a (very) different atmospheric state

2. There is no “correct” process ordering... and process order has a big impact on model behavior

3. Placement of macrophysics, microphysics, and radiation are the main determinants of model behavior
Background

1. Processes see different states
2. Process ordering has a big impact
3. macro/micro/rad are most important

- in EAM, most processes act on the state returned by the process before it (called sequential-update splitting)

Process ordering in EAM v0

- Fluid Dynamics
- Deep Convection
- Shallow Convection
- Macrophysics
- Microphysics
- Surface Scheme
- Radiation
- Turbulence
Proof that Processes See Very Different States

• The model state changes a lot from process to process (see Fig)
  • LWP and IWP change by a factor of 2 between processes!

Fig: liquid water path (LWP, red) and ice water path (IWP, blue) after selected processes in EAM v0 when using the default (30 min) \( \Delta t \)

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Mathematically, splitting differences $\propto$ model timestep ($\Delta t$)... See Fig.

$\Rightarrow$ Large state differences between processes are due to using a large $\Delta t$

We can’t afford to use appropriately small $\Delta t$... but can we afford not to?

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Evidence that there is no “Correct” Process Order

- There is wisdom to certain orders, but no rules that I know of

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- GFDL AM3
- EAM v1

Radiation affects Turbulence, which influences Surface Schemes. Shallow and Deep Convection can be handled separately or in parallel.

Fig: Process ordering for other models
A total of $5! = 120$ 1 yr runs with prescribed year 2000 SST and other forcings are conducted for all possible process orderings.

Two-letter keys for each process are used for efficient labeling.

Runs are clustered based on similarity of their output (more later)

What is impact of Process Order? Let’s Just Try Them!

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Process Ordering Has a Big Impact!

- The default order isn’t the best: Ra-DC-SC-Ma-Mi is 2.2% better in RMSE and 0.2% better in global avg. error (averaged over all x-axis variables)

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What is the Impact on Climate Predictions?

Fig: 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. Default order shown with red square. CMIP5 spread from Ringer et al. (2014 GRL) is shown in green (ensemble envelope in dashed lines, interquartile range in box).

Results:
• A set of 21 x 1 yr “Cess” experiments were run with +4K SST to estimate the net climate feedback.

\[ \Delta N = F + \lambda \Delta T \quad \Rightarrow \quad \lambda \approx \frac{\Delta N}{\Delta T} \]

• The 21 cases were chosen based on having reasonable TOA energy balance

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Which Process Orderings Matter?

- Clusters with macro before micro (reds) are systematically different than those with micro first (blues)
  - Because macro provides micro with more condensate to work with

- Radiation placement is the next most important thing because:
  - Output is written during radiation
  - Our output is skewed towards radiation variables

![Graph showing LWP tendencies and process orderings](image)

Fig: Global average liquid water path (LWP) tendencies of each process (left) and total precipitation rate (right) for each of the 120 simulations in this study. Colors and offset correspond to cluster grouping.

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Conclusions:

1. Each process acts upon a (very) different atmospheric state
   - This reflects large numerical errors and can confuse interpretation

2. There is no “correct” process ordering... and process order has a big impact on model behavior
   - Is this a large source of CMIP inter-model spread?

3. Placement of macrophysics, microphysics, and radiation are the main determinants of model behavior
   - Careful thought should go into deciding how these processes are coupled
End
Theoretical Arguments for Process Orders

• Order processes slowest to fastest (says Beljaars... for sequential-tendency split)
• Do turbulence and surface coupling together because they are intertwined
• Mi can’t handle supersaturated vapor so do it directly after Ma
• Do Ma+Mi together because they are so closely related?
• Give Ra the most ‘realistic’ state because of its importance?
• Do output with Ra for the same reason?

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Why Should You Care? An Annecdote

I’ve always been baffled how EAM (like most models) can rain too much even though its LWP is too low... (see Table)

<table>
<thead>
<tr>
<th></th>
<th>Ocean-Ave LWP</th>
<th>Global-Ave Precip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs</td>
<td>~80 g/m² (NCAP)</td>
<td>~2.7 mm/day (GPCP)</td>
</tr>
<tr>
<td>EAM v0 model</td>
<td>50 g/m²</td>
<td>2.9 mm/day</td>
</tr>
</tbody>
</table>

Table: Global-ave liquid water path (LWP) and precipitation from the E3SM v0 model.

This study solves that dilemma by pointing out that LWP used to calculate precipitation is ~2x higher than provided in output (see Fig)

Fig: LWP and IWP after selected processes in EAM v0 using default Δt

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Conclusions:

• Interpreting results requires understanding of where output is written
• Splitting errors are large at typical $\Delta t$
• While there’s some logic to process ordering, there’s no definitive best practice
  • Process order has a big impact on things we care about
  • Surprisingly, the default ordering doesn’t have best skill even though it is the result of years of tuning! Is doing radiation after dynamics always best?

Questions:

• Are these results obvious?
• Are some orderings so strange that we shouldn’t consider them?
  • For example, should we always assume that micro follows macro?
Climate predictions with Ma+Mi as a unit

- Subsetting climate change runs to cases where micro directly follows macro has little effect on ensemble spread