MODERNIZATION OF THE E3SM SINGLE COLUMN MODEL

Peter Bogenschutz, Peter Caldwell, and Aaron Donahue

Lawrence Livermore National Laboratory, Livermore, CA

Wuyin Lin

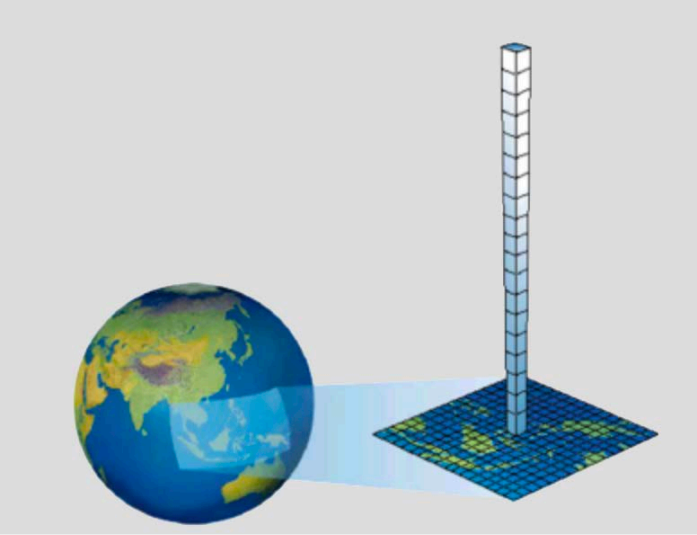
Brookhaven National Laboratory, Upton, NY

AMWG, February 2018, Boulder, CO

This work is funded by the ACME Software Modernization CMDV Project

This work was performed under the auspices of the U.S. Department of Energy by LLNL under contract DE-AC52-07NA27344. LLNL IM: LLNL-PRES-746033

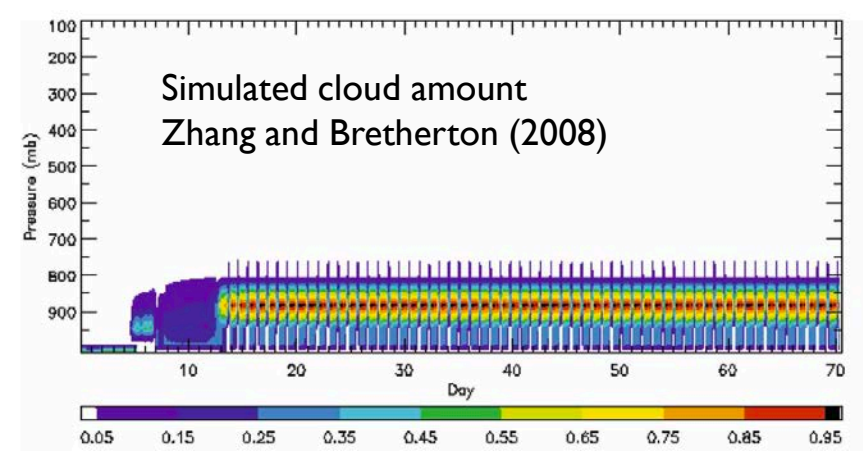
SINGLE COLUMN MODEL (SCM)

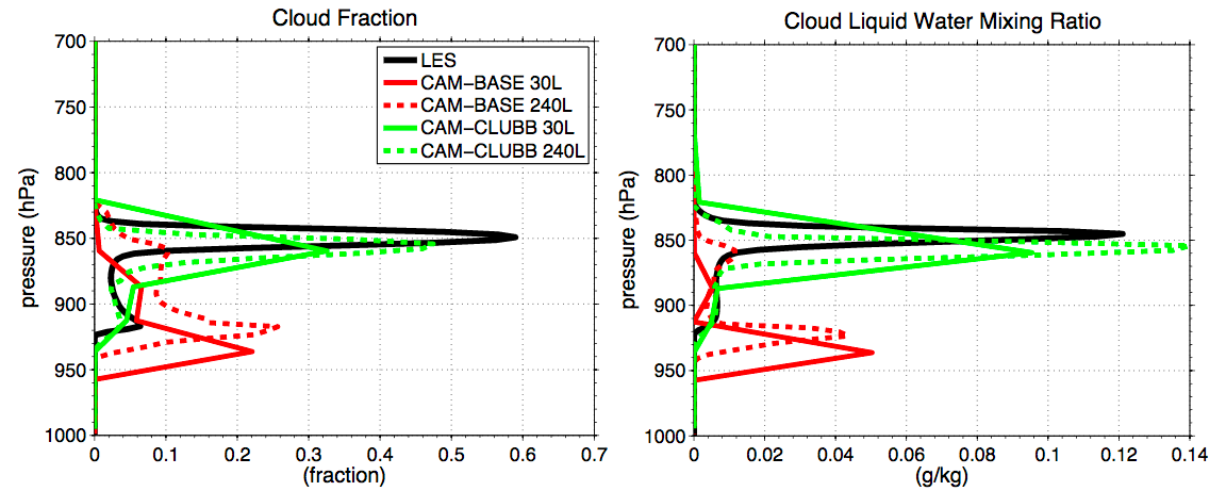


- The SCM is a mode of the E3SM model (branched off from CAM) where a single column of the atmosphere is run in isolation with prescribed atmospheric dynamics. Land fluxes can be prescribed or the land model can be run in this configuration
- The SCM is a very important tool for **development of model parameterizations** and can also be useful for **model assessment and tuning**
  - It allows developers to easily test a wide variety of model changes
  - Large number of SCM/GCSS/ARM cases exist that span a wide range of climate regimes

EXAMPLES OF SCM USEFULNESS

- Zhang and Bretheron (2008) used the SCM to show that cloud feedbacks in CAM3 were controlled by unphysical oscillations caused by interactions between convection and resolved-scale processes





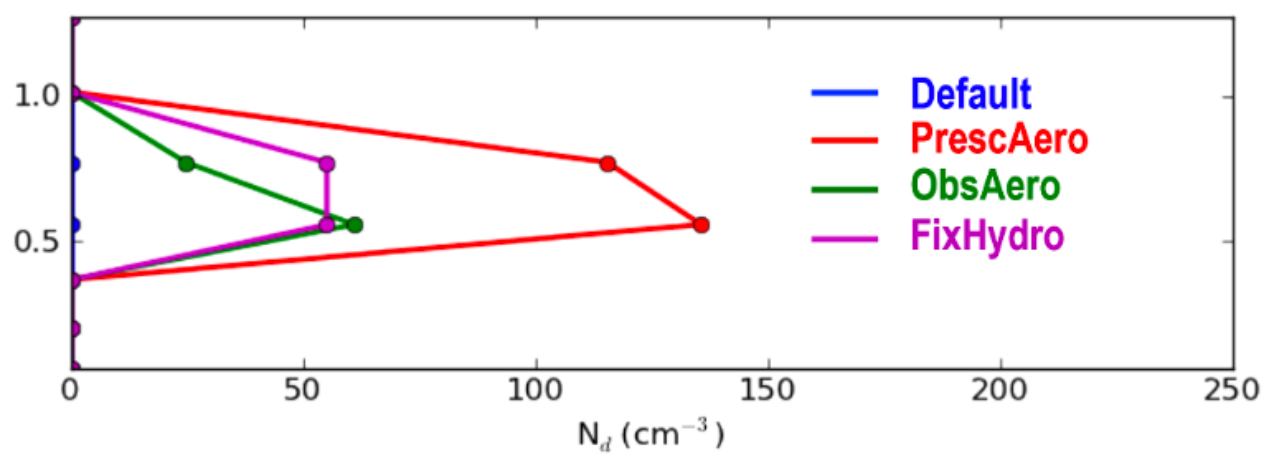
Bogenschutz et al. (2012) used SCM to perform vertical resolution sensitivity tests with CAM with a new parameterization (CLUBB)

SCM WOES

- We have addressed (or are currently addressing) the following issues:
  - Though a useful tool, the SCM has received minimal support. Often times, this results in a broken version of the model, which can be time consuming to sort out.
  - Scripts to run the SCM are often passed from user-to-user. Can result in improper case setups and unscientific solutions.
  - With the upgrade to a modal aerosol model, aerosols by default are initialized to zero. This can significantly effect the SCM solution.
  - Lack of ”idealizations” required for apples-to-apples comparison with select large eddy simulation (LES) intercomparison studies.
  - The E3SM SCM runs with a dynamical core (Eulerian) which is not the same as the full model (Spectral Element)
- Two fairly significant bugs found in the default E3SM SCM, originating from the branched off CAM SCM

E3SM SCM AEROSOL SPECIFICATION

Nd from DYCOMS-RF02 (drizzling marine stratocumulus)



From Lebassi-Habtezion and Caldwell (2014)

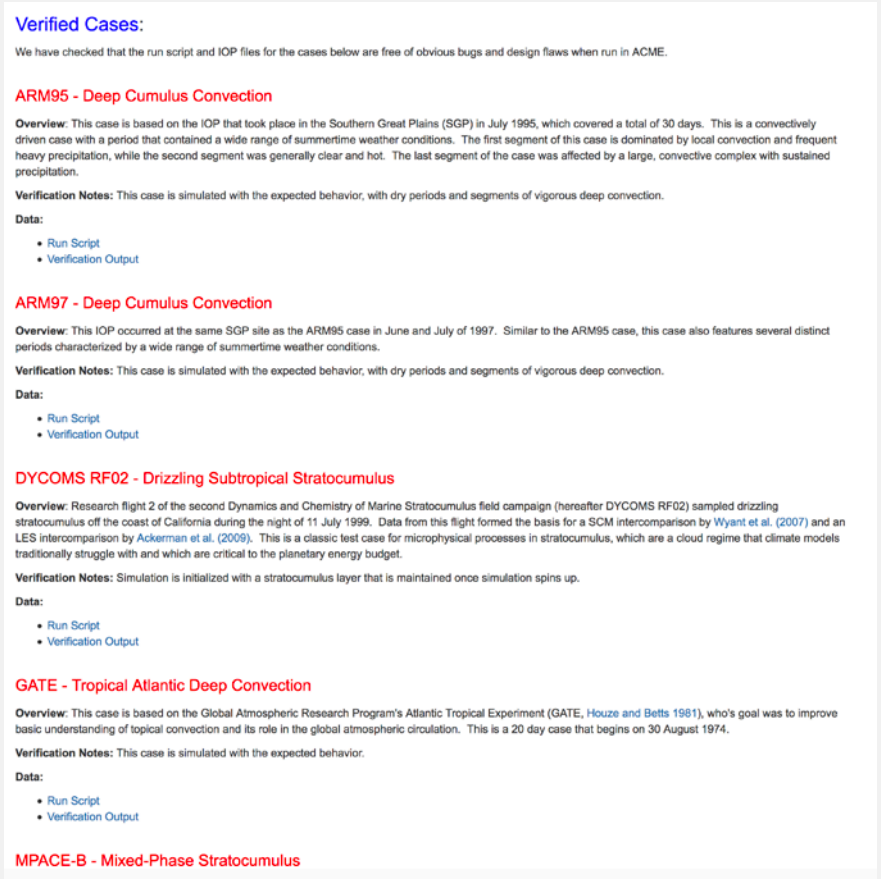
- E3SM/CAM SCM initializes all aerosol mass mixing ratios to zero
- This results in unrealistically low aerosol concentrations until surface emissions loft sufficient aerosol (process can take several days)
- Most GCSS boundary layer cloud cases are hours in length
- In addition, with E3SMv1 shallow convective clouds are tied to the MG microphysics
- SOLUTION: We implemented the modifications presented in Lebassi-Habtezion and Caldwell (2014)

E3SM SCM AEROSOL SPECIFICATION OPTIONS

- Aerosol specification in E3SM SCM may be accomplished via one of three methods as documented in BLP2014:
  - Fix cloud-droplet (Nd) and ice crystal (Ni) number concentration
  - Prescribed aerosols
    - Prescribes mass mixing ratios of aerosol species based on climatologies
    - Derived from a long prognostic-aerosol run
  - Observed mixing ratios
    - Apply the observed mixing ratios and size distributions to the aerosols (where available)
- E3SM SCM users are FORCED to select one of the three options for the model to run

E3SM SCM CASE LIBRARY

- Confluence How-To page documents the SCM cases library, in addition to obtaining relevant scripts
- Would like to make this a joint CESM/E3SM effort
- https://acme-climate.atlassian.net/wiki/display/Docs/ACME+Single-Column+Model+Case+Library
  - VERIFIED CASES: ARM95, ARM97, DYCOMS2-RF02, MPACE-B, RICO, TOGA-COARE, TWP-ICE, GATE, ARM-GCSS, ATEX, BOMEX, DYCOMS-RF01, RACORO
  - UNVERIFIED CASES: SPARTICUS
  - COMING SOON: MC3E, MAGIC, CGILS
  - Want a case not listed? Want to contribute a case? Let us know!
- Verified Case = We have checked that the run script and IOP files for the cases below are free of obvious bugs and design flaws when run in E3SM.



Verified Cases:

We have checked that the run script and IOP files for the cases below are free of obvious bugs and design flaws when run in ACME.

ARM95 - Deep Cumulus Convection

Overview: This case is based on the IOP that took place in the Southern Great Plains (SGP) in July 1995, which covered a total of 30 days. This is a convectively driven case with a period that contained a wide range of summertime weather conditions. The first segment of this case is dominated by local convection and frequent heavy precipitation, while the second segment was generally clear and hot. The last segment of the case was affected by a large, convective complex with sustained precipitation.

Verification Notes: This case is simulated with the expected behavior, with dry periods and segments of vigorous deep convection.

Data:

- Run Script
- Verification Output

ARM97 - Deep Cumulus Convection

Overview: This IOP occurred at the same SGP site as the ARM95 case in June and July of 1997. Similar to the ARM95 case, this case also features several distinct periods characterized by a wide range of summertime weather conditions.

Verification Notes: This case is simulated with the expected behavior, with dry periods and segments of vigorous deep convection.

Data:

- Run Script
- Verification Output

DYCOMS RF02 - Drizzling Subtropical Stratocumulus

Overview: Research flight 2 of the second Dynamics and Chemistry of Marine Stratocumulus field campaign (hereafter DYCOMS RF02) sampled drizzling stratocumulus off the coast of California during the night of 11 July 1999. Data from this flight formed the basis for a SCM intercomparison by Wyant et al. (2007) and an LES intercomparison by Ackerman et al. (2009). This is a classic test case for microphysical processes in stratocumulus, which are a cloud regime that climate models traditionally struggle with and which are critical to the planetary energy budget.

Verification Notes: Simulation is initialized with a stratocumulus layer that is maintained once simulation spins up.

Data:

- Run Script
- Verification Output

GATE - Tropical Atlantic Deep Convection

Overview: This case is based on the Global Atmospheric Research Program's Atlantic Tropical Experiment (GATE, Houze and Betts 1981), who's goal was to improve basic understanding of topical convection and its role in the global atmospheric circulation. This is a 20 day case that begins on 30 August 1974.

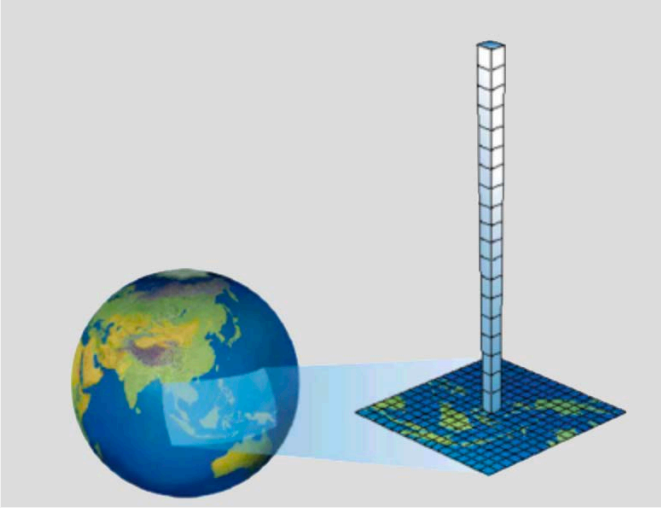
Verification Notes: This case is simulated with the expected behavior.

Data:

- Run Script
- Verification Output

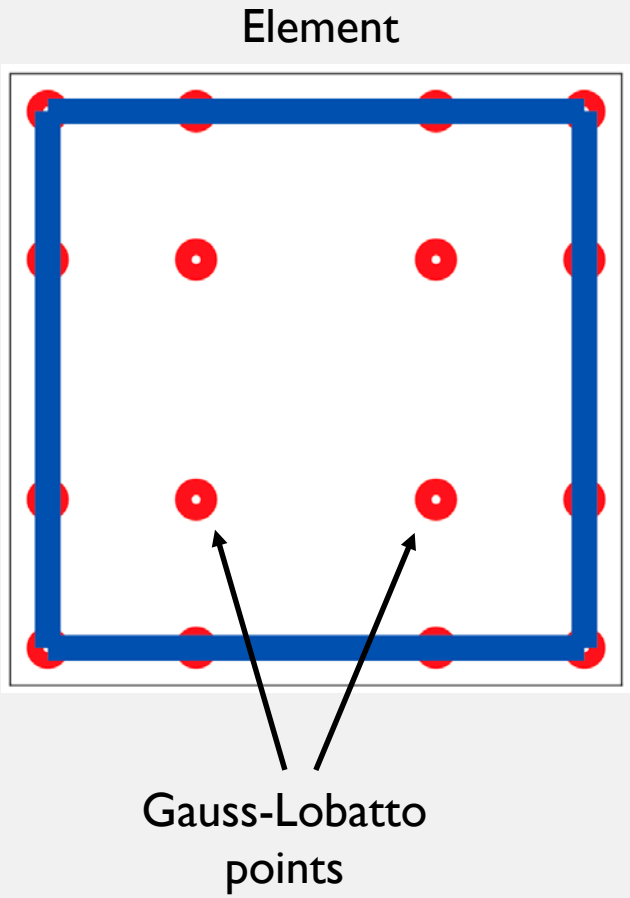
MPACE-B - Mixed-Phase Stratocumulus

SCM AND DY-CORE



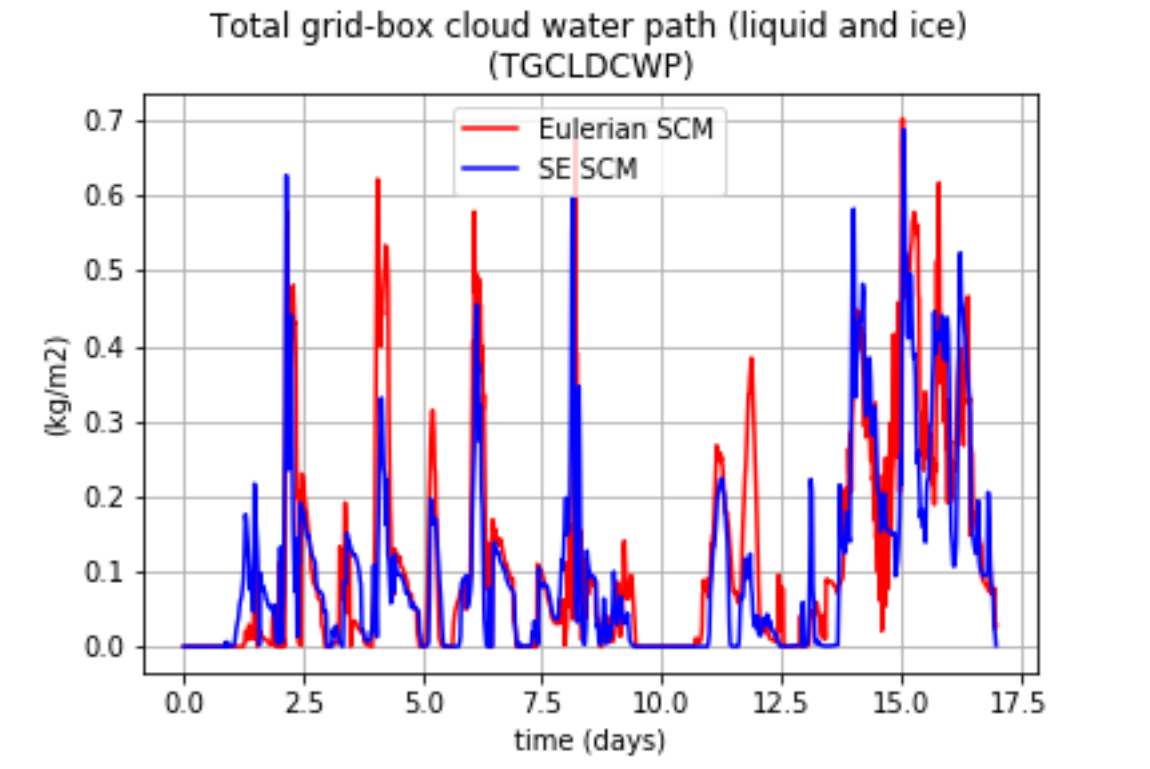
- The default E3SM and CAM SCM must be run with the Eulerian dynamical core, which is inconsistent with the dynamical core used in the full model
  - Inconsistencies with vertical advection, time stepping, and numerics
  - Inconsistencies with the "replay" or "global IOP" option
- Towards removing the ties with the Eulerian dynamical core we explored two options:
  - Enabling the SCM to run with the SE dynamical core
  - "Small planet" of identically forced small number of columns with IOP forcing driven through nudging routines

SPECTRAL ELEMENT SCM



- SE infrastructure makes it impossible to initialize one column (i.e. one Gauss-Lobatto point)
- The least invasive way to get around this is to initialize the entire ne4 grid, while initializing physics grid with only one column
- The only portion of the dynamics code called is SCM forecast routine and vertical advection (one column)
- All code that is shared between SE and Eulerian SCM (i.e. IOP reading routines, forecast routine, etc.) has been put into a shared directory
- SCM routines that are dy-core specific are put into an interface module that can be used as a template for introducing the SCM to new dy-cores

PROTOTYPE SE SCM



- First cut of the SE E3SM SCM shows qualitatively similar to results to the Eulerian SCM
  - B4B answers will never be expected due to differences in time stepping and numerics
- Currently the vertical advection calculation of the SE SCM is inconsistent to that used in SE core (last development step)
- Working towards a commit to E3SM master in the coming month for prototype SE SCM

WHERE ARE WE GOING?

- Produce finalized version of E3SM SE SCM
- Ability to extract boundary conditions from a GCM run and use it to exactly reproduce the behavior of a single column in SCM mode (a.k.a. "global-IOPs" or "replay" option)
- Design official SCM diagnostics package
- Slab-ocean SCM capability
- Functionality for Lagrangian cases (i.e. MAGIC, CGILS)
- Answer the science question "Does E3SM SCM provide a proxy of the full model? Why or why not?"