The Doubly Periodic SCREAM Configuration

Peter Bogenschutz¹, Chris Eldred², and Peter Caldwell¹

¹Lawrence Livermore National Laboratory, Livermore, CA
²Sandia National Laboratory, Albuquerque, NM

* Special thanks to: Noel Keen, Chris Terai, and Hassan Beydoun

E3SM All Hands, February 3rd, 2022

This work was performed under the auspices of the U.S. Department of Energy by LLNL under contract DE-AC52-07NA27344. LLNL IM release: LLNL-PRES-831276-DRAFT
Outline

• Introduction to Doubly-Periodic SCREAM (DP-SCREAM)
  – Motivation
  – Summary of development
  – DP-SCREAM case library
  – Availability and how to use

• An example of a scientific application of DP-SCREAM
  – Assessment of the horizontal resolution sensitivity of SCREAM

Figure courtesy Jungmin Lee
SCREAM

- SCREAM = Simple Cloud-Resolving E3SM Atmosphere Model (Caldwell et al. 2021)
- Target dx = 3 km globally, 128 vertical layers with a top at 40 km
- Contributed to DYAMOND2
- Moving to high resolution solves many long-standing problems with E3SM…

Figure courtesy Chris Terai. SCREAM DYAMOND2. White: liq+ice cloud water path. Colors: precip rate.
“Efficient Configurations” in GCMs

- Global cloud resolving models (GCRMs) (i.e. SCREAM) are far more computationally expensive than “conventional” ~100 km GCMs (i.e. E3SM).
- Even these relatively cheap conventional GCMs usually have a “single column model” (SCM) functionality.
- Isolates a single column on the globe (driven by “Intensive Observation Period” forcing).
- Energy Exascale Earth System Model (E3SM) SCM (Bogenschutz et al. 2020)
Single Column Models in GCMs

- Runs in a matter of minutes on a single node to enable fast feedback of GCM physics.
- SCMs insanely useful for:
  - Efficiently debugging the model.
  - Parameterization implementation/development (Bogenschutz et al. 2012; Park et al. 2014).
  - Performing perturbed parameter /ML applications.
Global Cloud Resolving Models

• SCREAM is “convection permitting”, meaning that clouds/convection are resolved over several columns.
• Thus, a SCM is not valid for GCRMs.
• However, SCREAM is a wildly expensive model so an “efficient” configuration to obtain fast feedback is necessary…

Figure from Caldwell et al. (2021)
Doubly-Periodic SCREAM (DP-SCREAM)

• DP-SCREAM represents a “single-point” three-dimensional cloud resolving model.
  – Size of domain and resolution determined by user.
  – Location and surface (i.e. land/ocean; radiation) determined from lat/lon of IOP case being used and ne30 grid.
  – Initialized as a collection of identical columns on a planar grid.
  – Random temperature perturbations applied to initial condition.
  – Boundary conditions are periodic in x & y.

• DP-SCREAM is NOT a true “limited area” model.

• Unlike SCM, DP-SCREAM “exercises” the entire model (i.e. physics AND dynamics).
DP-SCREAM Development

- A two-step parallel effort:
  - **Infrastructure** (Bogenschutz):
    - Modifications to the SCM infrastructure to enable its use across multiple columns.
    - Use the lat/lon of the desired case for the entire domain.
  - **Planar HOMME** (Eldred):
    - Ability to run standalone HOMME dynamical core on doubly-periodic planar grids.
    - Uses shallow water (sweqx) and hydrostatic/non-hydrostatic primitive equations (preqx and theta-l) models.

- Final step of stitching these two aspects together and providing resources to make DP-SCREAM accessible to use.
DP-SCREAM Status

• DP-SCREAM development is complete and has been in “beta” testing mode for several months.
  • DP-SCREAM currently only available in SCREAM F90
  • C++ conversion will take place in 2022
• Official F90 “release” will occur in spring 2022.
• SCREAM evaluation team uses DP-SCREAM to efficiently replicate biases we see in the global model (i.e. “popcorn convection”).
Running DP-SCREAM

Welcome to the Doubly Periodic SCREAM (DP-SCREAM) configuration! This page should provide sufficient resources for you to run the DP-SCREAM. Should you encounter difficulties or questions Peter Bogenschutz (LLNL) is the main contact point (bogenschutz1@llnl.gov).

PLEASE NOTE DP-SCREAM is currently in beta testing mode and is only open to authorized users at this point. To gain access please email bogenschutz1@llnl.gov. Hence, this page is currently a work in progress.

Reference: Bogenschutz et al. 2022 (in preparation)
Access to: The DP-SCREAM Case Library
Access to: Scripts and Information for running DP-SCREAM
Access to: DP-SCREAM Diagnostics (coming soon!)

E3SM SCM wiki on Github (publicly viewable) is now supporting both E3SM SCM and DP-SCREAM.

Includes instructions on how to run DP-SCREAM and documents the case library.

Currently we provide support for 27+ cases that will run out of the box with E3SM SCM and DP-SCREAM.

Each case has short description and run script (checked out from repo).
Running DP-SCREAM

1) Users need the most up-to-date SCREAM repo
2) Users will checkout the SCM/DP-SCREAM script repo from Github
   - Each case will have a script
   - Each case set up to run dx=dy=3.3 km by default
User has complete freedom to modify this!

```bash
#!/bin/bash -f

# Set the name of your case here
setenv casename scream_dp_ARMS

# Set the case directory here
setenv casedirectory /p/bastre2/bogenschatz/ACMS_simulations

# Directory where code lives
setenv code_dir /g19/bogenschatz/code

# Code tag name
setenv code_tag SCREAM_DP

# Name of machine you are running on (i.e. cori, anvil, etc)
setenv machine quartz

# Name of project to run on, if submitting to queue
setenv projectname ecbHONE

# Set to debug queue?
# - Some cases are small enough to run on debug queues
# - Setting to true only supported for NERSC and Livermore Computing,
#   else user will need to modify script to submit to debug queue
setenv debug_queue false

# Set number of processors to use
set num_procs = 256

# Set wall time
set walltime = '05:00:00'

# SET DOMAIN SIZE AND RESOLUTION:
# - Note that these scripts are set to run with dx=dy=3.33 km
# which is the default SCREAM resolution.
# To estimate dx (analogous for dy):
# dx = domain_size_x / (num_ne_x - 3)
# (There are 3x3 unique columns per element, hence the "3" factor)
# Set number of elements in the x/y directions
set num_ne_x = 20
set num_ne_y = 20

# Set domain length [m] in x/y direction
set domain_size_x = 268000
set domain_size_y = 268000

# BELOW SETS RESOLUTION DEPENDENT SETTINGS
# (Note that all default values below are appropriate for dx=dy=3.33 km and do not
# need to be modified if you are not changing the resolution)
```

User/machine specific information
Processor and wall time settings
Setting domain and resolution
### Continuous forcing:
- ARM SGP site from 2004-2015
- Darwin, Australia: summer seasons 2004-2007

### Boundary Layer Cases:
- DYCOMS-RF01 and RF02 (marine Sc)
- BOMEX and RICO (marine trade Cu)
- ATEX (Cu under Sc)
- ARM shallow Cu (continental Cu)
- RACORO (continental low clouds)
- MPACE, MPACE-B, ISDAC (mixed phase arctic clouds)
- GABLS (stable boundary layer)

### Deep Convection Cases:
- GATE, GATE-IDEAL, TOGA-COARE, DYNAMO (AMIE, Revelle, North Sounding), TWP-ICE (maritime deep convection)
- ARM97, ARM95, MC3E (continental deep convection)
- LBA (shallow to deep transition, continental)
- SPARTICUS (cirrus cloud)
- Radiative Convective Equilibrium (RCE)

### Coming Soon:
- Cold air outbreak (COMBLE)
- Southern ocean clouds (SOCRATES)
- Others needed? Let me know!

*Case contributors: Shuaiqi Tang, Shaocheng Xie, Cheng Tao, Yunyan Zhang, Peter Bogenschutz*
Rapid Feedback by DP-SCREAM

• Cost of a boundary layer cloud case
  – 50 km x 50 km horizontal domain size
    • At dx=dy=3.3 km to run for one simulated day: 4 minutes on ONE node
    • Compared to E3SM SCM cost of: 2 minutes on ONE node

• Cost of a deep convection case
  – Generally requires larger domain size (200 km x 200 km)
    • At dx=dy=3.3 km to run for one simulated day: 4 minutes on 6 nodes

• Cost of one simulated day of SCREAMv0:
  – One simulated day: ~ 5 hours on 1536 nodes

*machine used is cori-knl for all timings
DP-SCREAM Scientific Application

- DP-SCREAM allows the user to determine the domain size and resolution on the fly
  - Changing resolution in global models requires time consuming generation of many input files
- Thus, we can use DP-SCREAM to assess the horizontal resolution sensitivity of SCREAM
  - Is SCREAM scale aware (i.e. is it theoretically valid to run SCREAM at resolutions other than ~3 km)?
  - Is SCREAM scale insensitive (i.e. does the answer change when resolution changes)?
DP-SCREAM Horizontal Resolution Experiments

<table>
<thead>
<tr>
<th>CASE</th>
<th>Regime</th>
<th>Run Duration</th>
<th>Horizontal domain size</th>
</tr>
</thead>
<tbody>
<tr>
<td>GATE</td>
<td>Deep Cu</td>
<td>20 d</td>
<td>200 x 200 km</td>
</tr>
<tr>
<td>ARM97</td>
<td>Deep Cu</td>
<td>8 d</td>
<td>200 x 200 km</td>
</tr>
<tr>
<td>DYCOMS-RF01</td>
<td>Marine Sc</td>
<td>6 hr</td>
<td>50 x 50 km</td>
</tr>
<tr>
<td>MPACE-B</td>
<td>Mixed-phase</td>
<td>12 hr</td>
<td>50 x 50 km</td>
</tr>
<tr>
<td>RICO</td>
<td>Shallow Cu</td>
<td>24 hr</td>
<td>50 x 50 km</td>
</tr>
</tbody>
</table>

RED cases run with $dx = dy = 500$ m, 1.5 km, 3 km, 5 km
GREEN cases run with $dx = dy = 100$ m, 500 m, 1.5 km, 3 km, 5 km

All cases and resolutions are all run with the EXACT SAME code and tunable parameters.

* In the interest of time, will focus on results from DYCOMS-RF01 and ARM97 today
Marine Stratocumulus Case

- **DYCOMS-RF01**: Marine stratocumulus capped by a particularly strong inversion.
- **LES intercomparison**: Stevens et al. (2005)
- SCREAMv0 does a particularly good job with marine Sc.
  - These clouds are primarily SGS at 3km
- What about when resolution changes?
Running with SCREAM’s 128 vertical layers, which is still considered too coarse for marine Sc clouds (Bogenschutz et al. 2021; Lee et al. 2021).
DYCOMS-RF01: Turbulence Across Scales

Example of Scale Awareness

- Parameterized from SHOC
- Resolved by dynamics
Continental Deep Convective Case

• ARM97 case
• Deep convection over land as observed at the ARM Southern Great Plains (SGP) Site
• 27 day case widely used for SCMs and CRMs
• Here we focus on an 8 day subset from an active period
• Run with prescribed surface fluxes (could be interactive)
ARM97: Continental Deep Convection

Cloud Profiles

Result averaged from an 8-day active period starting on June 23, 1997
ARM97: Continental Deep Convection

Result averaged from an 8-day active period starting on June 23, 1997
Summary

- DP-SCREAM represents an “efficient” configuration of SCREAM that can be used for model development, debugging, and analysis.
- Using DP-SCREAM we determine that SCREAM is a scale aware model
  - We can run SCREAM at fine resolutions without the need of making structural changes (or “swapping” out parameterization).
- SCREAM is reasonably scale insensitive at the kilometer scale, but exhibits sensitivity outside of these bounds
  - Tuning may be required for very high resolution runs.