Simpler models within the CESM framework

OMWG webinar (Jul 6th)

Isla Simpson, Scott Bachman

People (in alphabetical order):

Scott Bachman, Jim Benedict, Frank Bryan, Patrick Callaghan, Amy Clement, Cheryl Craig, Brian Dobbins, Brian Eaton, Andrew Gettelman, Christiane Jablonowski, Peter Lauritzen, Steve Goldhaber, Brian Medeiros, Lorenzo Polvani, Kevin Reed, Isla Simpson, John Truesdale, Mariana Vertenstein, Xaoning Wu
Why is there a need for “Simpler Models”?
Earth System Models are continually increasing in complexity

“The health of climate theory/modelling in the coming decades is threatened by a growing gap between high-end simulations and idealized theoretical work. In order to fill this gap, research with a hierarchy of models is needed” – Held (2005), BAMS
Why is there a need for “Simpler Models”?

- Earth System Models are continually increasing in complexity

  “The health of climate theory/modelling in the coming decades is threatened by a growing gap between high-end simulations and idealized theoretical work. In order to fill this cap, research with a hierarchy of models is needed” – Held (2005), BAMS

- This increase in complexity typically comes with increased computational cost

  Release in 2010
  
  CAM4
  350
  x1
  
  CAM5
  ~1300
  x3.5
  
  CAM6
  ~3500
  x10
  
  SC-WACCM6
  ~7500
  x21
  
  WACCM6
  ~23000
  x65

  → Challenging to perform sensitivity tests, parameter sweeps etc needed for understanding and/or model development.
Two partially overlapping user groups
Two partially overlapping user groups

Climate Dynamicists

- Looking to gain a comprehensive theoretical understanding of the full system
- Simpler models are cheap to run
- Simpler models are easy to perturb
  - Allows for many perturbation experiments and parameter sweeps to explore sensitivities and gain that theoretical understanding in an idealized setting
## Two partially overlapping user groups

<table>
<thead>
<tr>
<th>Climate Dynamicists</th>
<th>Model developers</th>
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<tbody>
<tr>
<td>• Looking to gain a comprehensive theoretical understanding of the full system</td>
<td>• Idealized test cases for model numerics/tracer transports etc</td>
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<td>• Simpler models are cheap to run</td>
<td>• Debugging during dynamical core or physics parameterization development</td>
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<td>• Simpler models are easy to perturb</td>
<td>• Explore tuning sensitivities</td>
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<td>• Intercomparison of model components in an idealized setting</td>
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A brief history of CESM simpler models…

- Spearheaded by Amy Clement and Lorenzo Polvani, an effort to include supported idealized configurations within CESM began in 2014
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Google analytics page views of all CESM simpler models web-pages

(Number of views: all pages = 26199, welcome page = 8499, aquaplanet = 3278, dynamical core = 2685)
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- Configurations and a dedicated website (www.cesm.ucar.edu/models/simpler-models/) started to become available in 2015.
- The number of available configurations is growing steadily.

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Atmospheric idealized modelling
The atmospheric model hierarchy

1. CAM
2. Aquaplanet
3. RCE World
4. Gray Radiation Aquaplanet
5. Dynamical Core Aquaplanet
6. Dry Dynamical Core
7. Shallow Water Barotropic Models
   Stationary Wave Models
The atmospheric model hierarchy

- **Available CESM2.0 and later**
- **Available CESM2.1 and later**
- **Available in CESM2.1.3 and later**
- **Coming soon CESM2.?**
- **Not Available**

---

**Dry Dynamical Core**

**Dynamical Core with Idealized moisture**

**Gray Radiation Aquaplanet**

**RCE World**

**Aquadplanet**

**CAM**

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**Shallow Water Barotropic Models**

**Stationary Wave Models**

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[Available in CESM2.1.3 and later]

[Not Available]

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NCAR

[www.cesm.ucar.edu/models/simpler-models/](http://www.cesm.ucar.edu/models/simpler-models/)
Single Column Atmospheric Model

\[
\frac{D\theta}{Dt} = Q
\]

Dynamics

Convection Scheme

Moist Processes

Physical Parameterizations

Land (CLM)

Prescribed SSTs or coupled ocean

Prescribed sea-ice or coupled sea-ice

Gravity wave drag

Surface Fluxes

Stresses due to sub-grid orography

Radiative Transfer

Cloud Physics
Single Column Atmospheric Model

Prescribed Circulation

Land (CLM)

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Radiative Transfer

www.cesm.ucar.edu/models/simpler-models/scam/index.html
The Single Column Atmospheric Model (SCAM)

(Andrew Gettelman and John Truesdale)

A complete representation of the column physics, but atmospheric circulation and associated advection terms etc are prescribed

Fully functioning in CESM2.

Containerized version also available with accompanying jupyter lab tutorial and visualization tool (Brian Dobbins)
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A couple SCAM is also under development (SCESM) – Andrew Gettelman and John Truesdale
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- Dry Dynamical Core
- Dynamical Core with Idealized moisture
- Gray Radiation Aquaplanet
- RCE World
- Aquaplanet
- CAM
- Single Column Atmospheric Model (SCAM)
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www.cesm.ucar.edu/models/simpler-models/
Dry dynamical core, Held-Suarez configuration

\[ \frac{D \theta}{Dt} = Q \]

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www.cesm.ucar.edu/models/simpler-models/dry-dynamical-core.html
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Dry dynamical core, Held-Suarez configuration

\[ \frac{D \theta}{Dt} = Q \]

Newtonian Relaxation of the Temperature field toward a specified equilibrium profile:

\[ \frac{\partial T}{\partial t} = \cdots - \frac{T - T_{EQ}}{\tau} \]

Linear drag on wind at the lowest levels:

\[ \frac{\partial \vec{v}}{\partial t} = \cdots - k_v \vec{v} \]
Dry dynamical core, Held-Suarez configuration

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Following Held and Suarez (1994)

A Proposal for the
Intercomparison of the
Dynamical Cores of Atmospheric
General Circulation Models

www.cesm.ucar.edu/models/simpler-models/dry-dynamical-core.html
Dry dynamical core, Held-Suarez configuration

\[ \frac{D \theta}{Dt} = Q \]

Dynamics

Newtonian Relaxation of the Temperature field toward a specified equilibrium profile

\[ \frac{\partial T}{\partial t} = \cdots - \frac{T - T_{EQ}}{\tau} \]

Linear drag on wind at the lowest levels

\[ \frac{\partial \vec{v}}{\partial t} = \cdots - k_v \vec{v} \]

Following Held and Suarez (1994)

Extremely cheap to run
Very easy to perturb

www.cesm.ucar.edu/models/simpler-models/dry-dynamical-core.html
Moist Held-Suarez (Thatcher and Jablonowski 2016)

\[ \frac{D \theta}{Dt} = Q \]

Newtonian Relaxation of the Temperature field toward a specified equilibrium profile

\[ \frac{\partial T}{\partial t} = \cdots - \frac{T - T_{EQ}}{\tau} \]

Linear drag on wind at the lowest levels

\[ \frac{\partial \vec{v}}{\partial t} = \cdots - k_v \vec{v} \]
Moist Held-Suarez (Thatcher and Jablonowski 2016)

Dynamics

\[
\frac{D\theta}{Dt} = Q
\]

Newtonian Relaxation of the Temperature field toward a specified equilibrium profile

\[
\frac{\partial T}{\partial t} = \cdots - \frac{T - T_{EQ}}{\tau} + Q
\]

Linear drag on wind at the lowest levels

\[
\frac{\partial \mathbf{v}}{\partial t} = \cdots - k_v \mathbf{v}
\]

Evaporation from a water covered Earth using simple bulk formulae

Moisture moves around with the circulation

When specific humidity > 100% relative humidity → condensation and precipitation with associated diabatic heating

www.cesm.ucar.edu/models/simpler-models/moist_hs/index.html
The atmospheric model hierarchy

- **Dry Dynamical Core**
- **Dynamical Core with Idealized moisture**
- **Gray Radiation Aquaplanet**
- **RCE World**
- **CAM**
- **Aquaplanet**
- **Single Column Atmospheric Model (SCAM)**
- **Available CESM2.0 and later**
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[More information](www.cesm.ucar.edu/models/simpler-models/)
Gray Radiation Aquaplanet (Frierson et al 2006)

Dynamics

\[ \frac{D\theta}{Dt} = Q \]

Physical Parameterizations

Convection Scheme

Moist Processes

Cloud Physics

Radiative Transfer

Land (CLM)

Prescribed SSTs or coupled ocean

Prescribed sea-ice or coupled sea-ice

Gravity wave drag

Surface Fluxes

Stresses due to sub-grid orography
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Dynamics

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Physical Parameterizations

Slab ocean aquaplanet
\[ \frac{D\theta}{Dt} = Q \]

Gray Radiation Aquaplanet (Frierson et al 2006)

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\[ \frac{D \theta}{Dt} = Q \]

Dynamics

Optional

Convection Scheme

Moist Processes

Physical Parameterizations

Slab ocean aquaplanet

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Gray Radiation Aquaplanet (Frierson et al 2006)

\[
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Dynamics

Convection Scheme

Surface Fluxes

Optional Simple condensation and associated diabatic heating (as Moist Held-Suarez)

Physical Parameterizations

Radiative Transfer

Slab ocean aquaplanet

Dynamics

Optional Simple condensation and associated diabatic heating (as Moist Held-Suarez)

Physical Parameterizations

Radiative Transfer

Slab ocean aquaplanet
Gray Radiation Aquaplanet (Frierson et al 2006)

\[ \frac{D \theta}{Dt} = Q \]

Dynamics

Optional

Simple condensation and associated diabatic heating (as Moist Held-Suarez)

Convection Scheme

Moist Processes

Simple gray radiation. Incoming shortwave and 1 longwave band with a uniform prescribed longwave absorber. Water vapor is not seen by the radiation scheme

Slab ocean aquaplanet

Physical Parameterizations

Surface Fluxes

Radiative Transfer
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RCE World
Gray Radiation Aquaplanet
Dynamical Core
Dynamical Core with Idealized moisture
Dry Dynamical Core
Shallow Water Barotropic Models Stationary Wave Models

www.cesm.ucar.edu/models/simpler-models/
Radiative Convective Equilibrium world (RCE-world)

Dynamics

\[ \frac{D\theta}{Dt} = Q \]

Convection Scheme

Moist Processes

Cloud Physics

Physical Parameterizations

Surface Fluxes

Gravity wave drag

Stresses due to sub-grid orography

Radiative Transfer

Land (CLM)

Prescribed SSTs or coupled ocean

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Dynamics

Convection Scheme

Moist Processes

Cloud Physics

Radiative Transfer

Physical Parameterizations

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Dynamics

\[ \frac{D\theta}{Dt} = Q \]

Physical Parameterizations

Convection Scheme

Moist Processes

Cloud Physics

Radiative Transfer

Spatially uniform prescribed SSTs

Surface Fluxes

www.cesm.ucar.edu/models/simpler-models/rce/index.html
Radiative Convective Equilibrium world (RCE-world)

Dynamics

\[ \frac{D\theta}{Dt} = Q \]

Spatially uniform prescribed SSTs

Surface Fluxes

Convection Scheme

Moist Processes

Cloud Physics

Physical Parameterizations

Radiative Transfer

No spatial gradients in insolation

www.cesm.ucar.edu/models/simpler-models/rce/index.html
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Dynamics

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Physical Parameterizations

Convection Scheme

Moist Processes

Cloud Physics

Radiative Transfer

Spatially uniform prescribed SSTs

Surface Fluxes

No spatial gradients in insolation

NO ROTATION

www.cesm.ucar.edu/models/simpler-models/rce/index.html
Radiative Convective Equilibrium world (RCE-world)

- Following RCE-MIP protocols
- Useful for studying clouds, convection, climate sensitivity, convective aggregation

Spatially uniform prescribed SSTs

- Cloud Physics
- No spatial gradients in insolation

No rotation

www.cesm.ucar.edu/models/simpler-models/rce/index.html

(Dynamics)

\[
\frac{D\theta}{Dt} = Q
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**Dynamics**

Convection Scheme

Moist Processes

Cloud Physics

Radiative Transfer

**Physical Parameterizations**

Gravity wave drag

Surface Fluxes

Stresses due to sub-grid orography

**Land (CLM)**

Spatially uniform prescribed SSTs

Prescribed sea-ice or coupled sea-ice

**The Aquaplanet**
Dynamics

\[ \frac{D\theta}{Dt} = Q \]

Physical Parameterizations

Convection Scheme

Moist Processes

Cloud Physics

Radiative Transfer

Water-covered Earth

Prescribed SSTs or Slab Ocean

Surface Fluxes

www.cesm.ucar.edu/models/simpler-models/aquaplanet.html
The Aquaplanet

Dynamics

\[ \frac{D\theta}{Dt} = Q \]

Physical Parameterizations

- Convection Scheme
- Moist Processes
- Cloud Physics

Water-covered Earth

Prescribed SSTs or Slab Ocean

Surface Fluxes

Prescribed SST or slab ocean

Easy switch between Aquaplanet Experiment SST profiles (Neale and Hoskins 2000) or user-specified SSTs.

CAM4, CAM5 or CAM6 physics.

(Brian Medeiros, Jim Benedict, Dave Williamson Jerry Olson)

www.cesm.ucar.edu/models/simpler-models/aquaplanet.html
Next Steps
Planned implementation of SLIM (Simple Land Interface Model)

- An idealized bucket land model has been developed. (Lagüe, Bonan and Swann (2019))

- Bucket model with specified surface properties

- Code is not release ready.

- Should be engineered into a release branch in the fall.

*Will be useful for idealized land-atmosphere coupling studies and will greatly simplify the set-up of idealized coupled atmosphere-ocean configurations.*
Ongoing coupled aquaplanet efforts

(Xiaoning Wu, Scott Bachman, Frank Bryan, Gustavo Marques, Kevin Reed, Christopher Wolfe)

- CAM4 atmosphere (~1 deg)
- MOM6 ocean (~2 deg), 4000m depth, symmetric bottom topography
- CICE sea ice
- CLM5 land
- Initialization using an idealized ocean climatology from Pedro Di Nezio
A plan to bring this all together
Development of infrastructure to simplify coupled modelling

Cyberinfrastructure for streamlining coupled, simplified climate modelling within the Community Earth System Model, NSF CSSI (PI’s: Scott Bachman, Isla Simpson, Mariana Vertenstein, Gokhan Danabasoglu).

Typically, users don’t want to run an out-of-the-box idealized configuration..

We will:

(1) Develop a Simpler Models query tool to allow users to easily understand which simpler model configurations are available and supported, their compatibilities, different options (e.g., physics packages)

(2) Develop infrastructure for customization of ocean basin and land geometries (overlaps with needs of the Paleoclimate community)

(3) Provide a toolchain for seamless model setup (components, grids, domain, physics) among the simpler-model hierarchies.
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Experiment idea
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Toolkits and information needed to develop desired configuration
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Experiment idea

Toolkits and information needed to develop desired configuration

Step-by-step guidance for seamless model set-up
Development of infrastructure to simplify coupled modelling

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Conclusions

- The atmospheric model hierarchy available within CESM has expanded considerably since 2014.

- Next steps are to extend our capabilities in coupled idealized modelling and customization tool kits, inc. cubed sphere grid topology (w/ A. Adcroft), ocean bathymetry tool (Altuntas).

- At present, coupled idealized modelling doesn’t really have a home. ISCA (University of Exeter) is a modelling framework that is widely used for idealized atmosphere modelling. MIT GCM is a modeling framework that is widely used for idealized ocean modelling.

- Resources are limited, particularly software engineering resources and these resources are used for both the comprehensive CESM and idealized models. (So far this effort has been funded by some supplemental funding from NSF Climate and Large Scale Dynamics and base funds to NCAR. Now, we are able to expand our coupled capabilities and implement SLIM with additional NSF funding.)

- We hope to see continued and increased use of the idealized configurations within CESM to ensure their continued support.

- Please get in touch if you are interested in being a guinea pig for testing the new coupled model toolkits as they become available (bachman@ucar.edu, islas@ucar.edu)