Simpler Models in CESM

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“Atmospheric”

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CESM components:

- Atmosphere (CAM)
- Ocean (POP)
- Land (CLM)
- Land Ice (GLC)
- Sea Ice (CICE)
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Dynamics

\[ \frac{D\theta}{Dt} = Q \]
CESM components:

**Atmosphere (CAM)**

- Dynamics
  \[ \frac{D \theta}{Dt} = Q \]
- Convection Schemes
- Moist Processes
- Gravity Wave Drag
- Surface Fluxes
- Radiative Transfer
- Cloud Physics
- Physical Parameterizations
- Stresses due to sub-grid orography
CESM components:

- Atmosphere (CAM)
- Ocean (POP)
- Land (CLM)
- Land Ice (GLC)
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Present day, annual mean climatologies as simulated by CESM

- CESM1 Precip Climatology (1979-2005)
- CESM1 700hPa U climatology (1979-2005)
(2070-2099) – (1979-2005) changes as simulated by CESM under RCP8.5
Problems:

- CESM is complicated (everything is changing all at once)
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  - Momentum balance
  - Moisture balance
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- To obtain this climate, we needed to use this...
How can we pull it all apart and understand it?
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(1) Detailed diagnosis of model output
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(2) Using simplified versions of CESM.
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(3) Performing idealized experiments with the comprehensive version of CESM.
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Simpler Models: stripped down versions of CESM that only contain certain components and/or idealized representation of other components.
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**PRO’s**
- Easy to perturb

**CON’s**
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<thead>
<tr>
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Simpler Models: stripped down versions of CESM that only contain certain components and/or idealized representation of other components.

**PRO’s**
- Easy to perturb
- Allows for idealized experiments to identify causal pathways
- Cheap

**CON’s**
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**PRO’s**
- Easy to perturb
- Allows for idealized experiments to identify causal pathways
- Cheap
- Allows for parameter sweeps to identify sensitivities

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Simpler Models: stripped down versions of CESM that only contain certain components and/or idealized representation of other components.

**PRO's**
- Easy to perturb
- Allows for idealized experiments to identify causal pathways
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- Allows for parameter sweeps to identify sensitivities

**CON's**
- Less realistic
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- Easy to perturb
- Allows for idealized experiments to identify causal pathways
- Cheap
- Allows for parameter sweeps to identify sensitivities

**CON’s**
- Less realistic

**Advice:**
- Always keep your eye on the real world/full CESM
- Use the model hierarchy
- Know your model’s limitations
The Atmospheric Model Hierarchy

- CAM
- Aquaplanet
- Single Column Atmospheric Model (SCAM)

- Increasing Complexity
- Idealized Moist Physics
- Dry Dynamical Core

- Shallow Water
- Barotropic Models
- Stationary Wave Models
The Dry Dynamical Core

Dynamics

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

Convection Schemes

Moist Processes

Physical Parameterizations

Cloud Physics

Land (CLM)

Prescribed SSTs

Prescribed ICE

Gravity Wave Drag

Surface Fluxes

Radiative Transfer

Stresses due to sub-grid orography
The Dry Dynamical Core

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Dynamics

$$\frac{D\theta}{Dt} = Q$$

Newtonian Relaxation of the temperature field toward a specified equilibrium profile

$$\frac{\partial T}{\partial t} = \cdots - \frac{T - T_{eq}}{\tau}$$

Linear drag on wind at the lowest levels

$$\frac{\partial \dot{v}}{\partial t} = \cdots - k_v \dot{v}$$
Out of the box: $T_{eq}$ and frictional drag following Held and Suarez (1994)
Flat sphere default
Perpetual equinox conditions

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

Isaac M. Held*
and Max J. Suarez**
The Dry Dynamical Core

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Relaxation T profile
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500hPa Vorticity in a Held-Suarez simulation
The Dry Dynamical Core

Documented at https://www2.cesm.ucar.edu/models/simpler-models/dynamical-core-test/held-suarez  !!still under construction!!

Contact: Isla Simpson (islas@ucar.edu)
The Dry Dynamical Core

Example uses:

- Tropospheric response to stratospheric cooling (ozone hole like)

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Chan and Plumb (2009)
The Dry Dynamical Core

Good for:

- Problems in large scale atmospheric dynamics that are not highly dependent on moisture
  
  e.g., mid-latitude jet dynamics, eddy-mean flow interactions, tropical-extra-tropical connections, stratosphere-troposphere coupling
The Dry Dynamical Core

Good for:
- Problems in large scale atmospheric dynamics that are not highly dependent on moisture
  e.g., mid-latitude jet dynamics, eddy-mean flow interactions, tropical-extra-tropical connections, stratosphere-troposphere coupling

Not good for:
- Aspects of the atmospheric circulation where moisture is key e.g. Hadley circulation, tropical dynamics
The Aquaplanet

Dynamics
\[ \frac{D\Theta}{Dt} = Q \]

Convection Schemes
Moist Processes

Physical Parameterizations

Gravity Wave Drag

Water covered Earth
Prescribed SSTs
Or Slab Ocean

Surface Fluxes

Stresses due to sub-grid orography

Radiative Transfer

Cloud Physics
The Aquaplanet

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

Water covered Earth
Prescribed SSTs
Or
Slab Ocean

Surface Fluxes

Convection Schemes
Moist Processes

Cloud Physics

Radiative Transfer

Physical Parameterizations

Gravity Wave Drag

Stresses due to sub-grid orography
Available out of the box with CAM4, CAM5 and CAM6 physics

Finite Volume Dynamical Core (1° and 2° horizontal resolution)

Prepetual Equinox, (seasonal cycle may be coming later)

Prescribed SSTs or Slab Ocean

Easy to modify SST profile
Aquaplanet will be documented at https://www2.cesm.ucar.edu/models/simpler-models/aquaplanet !!still under construction!!

Contact: Brian Medeiros (brianpm@ucar.edu)

AQUAPLANET

Summary

The aquaplanet configuration in CESM allows the user to run CAM above an entirely ocean covered surface. The surface model is essentially a data ocean model where SST has to be specified. There are a standard set based on the AquaPlanet Experiment project (Neale & Hoskins, Williamson). The advantage of an aquaplanet configuration is that it allows the user to run the full CAM parameterization suite while retaining much simpler surface conditions than the complex combination of land, ocean and sea-ice seen in the real world. This configuration is frequently seen as a bridging test of a GCM between more idealized dynamical core experiments with rudimentary representations of physical processes and and prescribed SST AMIP experiments. The CAM5 aquaplanet configuration is described by Medeiros et al. (2016).


David L. Williamson and Co-Authors, 2012: The APE Atlas. Technical report, National Center for Atmospheric Research. URL http://nldr.library.ucar.edu/repository/collections/TECH-NOTE-000-000-00...

CESM Options

Aquaplanet simulations can be run in CESM using the following compsets:
The Aquaplanet

Example uses: understanding the behaviour of clouds and precipitation and their coupling to the circulation

Stevens and Bony (2013)

Response of cloud radiative effects and precip to uniform SST warming of 4K
Example uses: sensitivity of hurricane formation to the latitude of the ITCZ

Merlis et al (2013) using GFDL-HiRAM (50km Resolution)

850hPa relative vorticity
White is positive (cyclonic)

~40% increase in # of cyclones per degree poleward shift of the ITCZ from 8N

Movies courtesy of Tim Merlis (McGill University)
The Atmospheric Model Hierarchy

Thatcher and Jablonowski (2016)
Like Held-Suarez, but with a simple representation of boundary layer fluxes of moisture and heat and a simple representation of diabatic heating from condensation of saturated air parcels.

Increasing Complexity

Dry Dynamical Core

Idealized Moist Physics

Aquaplanet

CAM

Single Column Atmospheric Model (SCAM)

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Cam

Aquaplanet

Idealized Moist Physics

Single Column Atmospheric Model (SCAM)

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Examine the behavior of physical parameterizations in a single column in the absence of dynamical feedbacks.
Summary

- Simpler versions of the model are an extremely useful tool for understanding the behavior of the comprehensive version of the model and to explore mechanisms and sensitivities.

- Make use of the model hierarchy to break down whatever problem you’re investigating, if there is a simpler model that is relevant.

- Get in touch if you are keen to develop your own simplified version of the model.

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For aquaplanet: Brian Medeiros, brianpm@ucar.edu