Idealized configurations within the atmosphere model (CAM)

People (in alphabetical order): Jim Benedict, Patrick Callaghan, Cheryl Craig, Amy Clement, Brian Eaton, Andrew Gettelman, Christiane Jablonowski, Jean-Francois Lamarque, Peter Lauritzen, Steve Goldhaber, Brian Medeiros, Lorenzo Polvani, Kevin Reed, Isla Simpson, John Truesdale, Mariana Vertenstein, Colin Zarzycki
The Community Atmosphere Model (CAM)

Dynamics

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

Physical Parameterizations

- Convection Schemes
- Moist Processes
- Cloud Physics
- Radiative Transfer
- Stresses due to sub-grid orography
- Surface fluxes
- Gravity Wave Drag

Land (CLM)

Prescribed SSTs

Prescribed ICE
The Community Atmosphere Model (CAM)

Dynamics

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

Physical Parameterizations

Convection Schemes

Moist Processes

Cloud Physics

Radiative Transfer

Land (CLM)

Prescribed SSTs

Prescribed ICE

Gravity Wave Drag

Surface fluxes

Stresses due to sub-grid orography
The Community Atmosphere Model (CAM)

Dynamics

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

Simple Physics

Simple Surface
The Community Atmosphere Model (CAM)

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

Dynamics

Convection Schemes

Moist Processes

Physical Parameterizations

Cloud Physics

Radiative Transfer

Stresses due to sub-grid orography

Gravity Wave Drag

Surface fluxes

Land (CLM)

Prescribed SSTs

Prescribed ICE

Radiative Transfer

SSTs

Prescribed

ICE
The Community Atmosphere Model (CAM)

Dynamics

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

Physical Parameterizations

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- Moist Processes
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- Surface fluxes
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Land (CLM)

Prescribed SSTs

Prescribed ICE
The Community Atmosphere Model (CAM)

Prescribed dynamics

Physical Parameterizations

Convection Schemes
Moist Processes

Land (CLM)
Prescribed SSTs
Prescribed ICE

Gravity Wave Drag

Surface fluxes

Stresses due to sub-grid orography

Cloud Physics
Radiative Transfer
Why? Who cares?

Climate dynamicists

- Gain a comprehensive understanding of dynamical processes in the climate system without complex physics e.g., wave-mean flow interactions, strat-tropi coupling
- Gain a comprehensive understanding of physical processes without the complicating dynamics e.g., understanding the behavior of convection under particular boundary forcings
- Cheap to run
- Easy to control/perturb
- Can add in complexity to understand the full system.

Dynamical Core developers + Parameterization developers

- Idealized test cases for dynamical core numerics and tracer transports without the complicating physics
- Test cases for model physics with prescribed dynamics (single column cases over a location during an intensive observation period)
- Useful for debugging during dynamical core and physics parameterization development.

Useful Teaching Tool
Over the last few years, in an effort motivated and lead by Lorenzo Polvani and Amy Clement a number of idealized configurations of CAM have been made available within CESM.

Some of these configurations were already there and used extensively by model developers (e.g., the dry dynamical core) and for these it was a case of cleaning them up, fully supporting them, making a compset and documenting them.

Others required more work...
The Atmospheric Model Hierarchy

- CAM
- Aquaplanet
- Full Dynamics
- Increasingly complex physics
- Full Physics
- Prescribed Dynamics
- Single Column Atmospheric Model (SCAM)

- Dry Dynamical Core
  - Shallow Water
  - Barotropic Models
  - Stationary Wave Models
  - Idealized Moist Physics
    - Idealized Dynamics and Physics
The Atmospheric Model Hierarchy

Dry Dynamical Core

- Shallow Water Models
- Barotropic Models
- Stationary Wave Models

Increasingly complex physics

- Full Dynamics
- Idealized Moist Physics
- Aquaplanet

- Idealized Dynamics and Physics
- Full Physics
- Prescribed Dynamics

Full Physics

Single Column Atmospheric Model (SCAM)

CAM
The Community Atmosphere Model (CAM)

Dynamics

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

Physical Parameterizations

Convection Schemes

Moist Processes

Cloud Physics

Radiative Transfer

Land (CLM)

Prescribed SSTs

Prescribed ICE

Gravity Wave Drag

Surface fluxes

Stresses due to sub-grid orography
The Community Atmosphere Model (CAM)

Dynamics

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

Physical Parameterizations

Convection Schemes
Moist Processes

Cloud Physics

Land (CLM)
Prescribed SSTs
Prescribed ICE

Gravity Wave Drag
Surface fluxes
Stresses due to sub-grid orography

Radiative Transfer
The Dry Dynamical Core

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

\[ \frac{\partial \vec{v}}{\partial t} = \cdots - k_v \hat{v} \]
Step 1: Set up the Held-Suarez Case

A Warm Starts simulation can be set up for the Held-Suarez by running the following command from the CESM model directory:

```bash
./سحبان /مجلة /نمذجة /بيئة /ساعد /سويز /منافع /نقطة /يتألف /من /نقطة /العمليات /العتمد /على /الاقتراض /الدولي /الدولي /الدولي /الدولي /الدولي
```

where the case directory ($CESMHOME/cesm/work/demos/models/ Modern Climate Variability/ Modern Climate Variability/ CESM/held-suarez) is specified by the user. For example, using your own home directory, you could run the following command:

```bash
./سحبان /مجلة /نمذجة /بيئة /ساعد /سويز /منافع /نقطة /يتألف /من /نقطة /العمليات /العتمد /على /الاقتراض /الدولي /الدولي /الدولي /الدولي /الدولي
```

Step 2: Configure the Held-Suarez Case

The configuration option "fset" is in the command above ensures that the model runs for 1,000 days. This can be modified to run for any other period using the following command:

```bash
./سحبان /مجلة /نمذجة /بيئة /ساعد /سويز /منافع /نقطة /يتألف /من /نقطة /العمليات /العتمد /على /الاقتراض /الدولي /الدولي /الدولي /الدولي /الدولي
```

Depending on how the job (n) is set up on the machine being used, it may be necessary to divide the simulation up into separate parts. To do this, set the --nset option to 1 to run the simulation in four separate chunks of length 1000 days, execute the following command:

```bash
./سحبان /مجلة /نمذجة /بيئة /ساعد /سويز /منافع /نقطة /يتألف /من /نقطة /العمليات /العتمد /على /الاقتراض /الدولي /الدولي /الدولي /الدولي /الدولي
```

Step 3: Set up and Build the Case

Set up and build the case by running the following commands from within $CESMHOME/cesm:

```bash
./سحبان /مجلة /نمذجة /بيئة /ساعد /سويز /منافع /نقطة /يتألف /من /نقطة /العمليات /العتمد /على /الاقتراض /الدولي /الدولي /الدولي /الدولي /الدولي
```

Step 4: Run the Case

```bash
./سحبان /مجلة /نمذجة /بيئة /ساعد /سويز /منافع /نقطة /يتألف /من /نقطة /العمليات /العتمد /على /الاقتراض /الدولي /الدولي /الدولي /الدولي /الدولي
```

Step 5: Validate the model output

By default, both monthly and 6-hourly anomalous fields are output from the simulation. The monthly anomaly files contain a number of standard fields and eddy fields that from the variable ERF, the temporal tendency associated with the relaxation toward the equilibrium temperature profile. There is also a non-vortex temperature tendency associated with the wind stress (SWH). This temperature tendency includes frictional heating due to associated with the energy of the mesoscale eddies. As for the time errors, the net time error is being applied on model levels, not pressure levels (see CESM documentation, section 6.3.17).

The 6-hourly anomalous fields consist of zonal and meridional winds (u, v), and temperature (T). The u and v fields were computed to produce the following plots from days 200 to 1300 of the simulation, using the 6-hourly anomalous fields.

![Example plots and scripts for validation](http://www.cesm.ucar.edu/models/simpler-models/held-suarez.html)
http://www.cesm.ucar.edu/models/simpler-models/held-suarez.html

Instructions on:

- Running with a different dynamical core
- Changing the vertical and horizontal resolution
- Running with topography
- Running with a different analytical relaxation temperature profile (Polvani and Kushner 2002 stratosphere as an example)
- Running with a relaxation temperature profile from netcdf

Modifying the default configuration

- Change the initial conditions
- Change the vertical resolution
- Running with a different dynamical core
- Change the output fields
- Adding In Topography
- Define a new history field e.g., the relaxation temperature profile
- Running with a different analytical relaxation temperature profile and damping settings e.g., the Polvani and Kushner (2002) setup
- Reading in a relaxation temperature profile from a netcdf file
The Atmospheric Model Hierarchy

Full Dynamics
Increasingly complex physics

CAM

Aquaplanet

Idealized Moist Physics

Dry Dynamical Core

Shallow Water
Barotropic Models
Stationary Wave Models

Issues for use with idealized ocean models
- No representation of surface stress (but that could be added)
- No moisture (no precipitation or evaporation)
- No radiation

Single Column Atmospheric Model (SCAM)

Increasingly complex physics

Full Physics
Prescribed Dynamics

Issues for use with idealized ocean models
- No representation of surface stress (but that could be added)
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Shallow Water

Barotropic Models

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Single Column Atmospheric Model (SCAM)

Full Physics
Prescribed Dynamics
The Atmospheric Model Hierarchy

- CAM
- Aquaplanet
- Full Dynamics
  Increasingly complex physics
- Idealized Moist Physics
  - Dry Dynamical Core
  - Shallow Water
  - Moist Held-Suarez
  - Barotropic Models
  - Stationary Wave Models
  - Idealized Dynamics and Physics
- Gray radiation
- Single Column Atmospheric Model (SCAM)
- Full Physics
  Prescribed Dynamics
The Atmospheric Model Hierarchy

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- Single Column Atmospheric Model (SCAM)
- Idealized Dynamics and Physics
The Community Atmosphere Model (CAM)

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

Dynamics

Physical Parameterizations

Convection Schemes

Moist Processes

Cloud Physics

Radiative Transfer

Land (CLM)

Prescribed SSTs

Prescribed ICE

Gravity Wave Drag

Surface fluxes

Stresses due to sub-grid orography
The Community Atmosphere Model (CAM)

Dynamics

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

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Radiative Transfer
The Dry Dynamical Core

Dynamics

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

Newtonian Relaxation of the temperature field toward a specified equilibrium profile

\[
\frac{\partial T}{\partial t} = \ldots - \frac{T - T_{eq}}{\tau}
\]

Linear drag on wind at the lowest levels

\[
\frac{\partial \vec{v}}{\partial t} = \ldots - k_v \vec{v}
\]
Newtonian Relaxation of the temperature field toward a specified equilibrium profile

\[
\frac{\partial T}{\partial t} = \ldots - \frac{T - T_{eq}}{\tau}
\]

Linear drag on wind at the lowest levels

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

Prescribed SST
Idealized representation of boundary layer fluxes of heat and moisture
Moisture that moves around with the dynamics.
Diabatic heating from condensation of saturated air parcels.
The Atmospheric Model Hierarchy

- CAM
- Aquaplanet
- Single Column
- Dry Dynamical Core
- Idealized Moist Physics
- Shallow Water
- Barotropic Models
- Stationary Wave Models

- Full Dynamics
- Increasingly complex physics
- Full Physics
- Prescribed Dynamics
- Moist Held-Suarez
- Idealized Dynamics and Physics

Issues for use with idealized ocean models
- No radiation
- Boundary layer fluxes are more simplified than in CAM.
  - Still Rayleigh drag for momentum
  - Simple surface fluxes of temperature and moisture e.g., no dependence on boundary layer stability profiles.

\[
\frac{\partial T_a}{\partial t} = \frac{C_H |v_a| (T_s - T_a)}{z_a} \quad \frac{\partial q_a}{\partial t} = \frac{C_E |v_a| (q_{sat,s} - q_a)}{z_a}
\]
The Atmospheric Model Hierarchy

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

Increasingly complex physics leads to:

- Full Dynamics
- Prescribed Dynamics

Starting with:

- Idealized Moist Physics
- Dry Dynamical Core
- Shallow Water
- Barotropic Models
- Stationary Wave Models
- Moist Held-Suarez
- Idealized Dynamics and Physics
- Gray radiation
The Atmospheric Model Hierarchy

- CAM
- Aquaplanet
- Full Dynamics
- Increasingly complex physics
- Idealized Moist Physics
- Dry Dynamical Core
- Shallow Water
- Moist Held-Suarez
- Barotropic Models
- Stationary Wave Models
- Idealized Dynamics and Physics
- Gray radiation
- Single Column Atmospheric Model (SCAM)
- Full Physics
- Prescribed Dynamics
Moist Held Suarez (Thatcher and Jablonowski 2016)

Dynamics

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

Newtonian Relaxation of the temperature field toward a specified equilibrium profile

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

Linear drag on wind at the lowest levels

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

Prescribed SST

Idealized representation of boundary layer fluxes of heat and moisture

Moisture that moves around with the dynamics.

Diabatic heating from condensation of saturated air parcels.
Dynamics

\[
\frac{D \theta}{Dt} = Q
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Newtonian Relaxation of the temperature field toward a specified equilibrium profile

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\frac{\partial T}{\partial t} = \ldots - \frac{T - T_{eq}}{\tau}
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Linear drag on wind at the lowest levels

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

Prescribed SST

Idealized representation of boundary layer fluxes of heat and moisture

Moisture that moves around with the dynamics.

Diabatic heating from condensation of saturated air parcels.

Gray radiation (Frierson et al 2006)
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

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

Mixed layer ocean

Idealized representation of boundary layer fluxes of heat and moisture

Moisture that moves around with the dynamics.

Diabatic heating from condensation of saturated air parcels.

Gray radiation (Frierson et al 2006)
Gray radiation (Frierson et al 2006)

**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**

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

**Mixed layer ocean**

- Idealized representation of boundary layer fluxes of heat and moisture
- Moisture that moves around with the dynamics
- Diabatic heating from condensation of saturated air parcels
Gray radiation (Frierson et al 2006)

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

Gray radiation.
Specified long wave absorber distribution
Radiation does not see water vapor
No clouds
Simplified Monin-Obhukov for surface fluxes

\[ \mathcal{T} = \rho_a C |v_a|v_a \]
\[ S = \rho_a c_p C |v_a|(\Theta_a - \Theta_s) \]
\[ E = \rho_a C |v_a|(q_a - q_s^*) \]

Prescribed SST
Idealized representation of boundary layer fluxes of momentum and moisture
Moisture that moves around with the dynamics.
Diabatic heating from condensation of saturated air parcels.
The Atmospheric Model Hierarchy

**Idealized Moist Physics**

- Full Dynamics
- Increasingly complex physics

**Dry Dynamical Core**

**Aquaplanet**

**Idealized Dynamics and Physics**

**Gray radiation**

**CAM**

**Single Column Atmospheric Model (SCAM)**

Considerations for idealized ocean models.
- It has radiation
- But much more simplified than CAM physics e.g., no clouds, no water vapor seen by the radiation scheme.
- Representation of surface fluxes is simplified compared to CAM.
The Atmospheric Model Hierarchy

- CAM
  - Aquaplanet
    - Idealized Moist Physics
      - Dry Dynamical Core
        - Shallow Water
        - Barotropic Models
        - Stationary Wave Models
          - Idealized Dynamics and Physics
            - Increasingly complex physics
          - Full Dynamics
            - Prescribed Dynamics
              - Full Physics
            - Single Column Atmospheric Model (SCAM)
The Atmospheric Model Hierarchy

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The Community Atmosphere Model (CAM)

Dynamics

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

Physical Parameterizations

Convection Schemes

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Radiative Transfer
The Community Atmosphere Model (CAM)

Dynamics

\[
\frac{D\theta}{Dt} = Q
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Physical Parameterizations

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Water covered Earth

Slab ocean or prescribed SST
The Community Atmosphere Model (CAM)

Dynamics

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

Currently available with CAM4, CAM5 and CAM6 physics in FV and SE dynamical cores.

Physical Parameterizations

Convection Schemes

Moist Processes

Cloud Physics

Gravity Wave Drag

Surface fluxes

Stresses due to sub-grid orography

Water covered Earth
Slab ocean or prescribed SST

Radiative Transfer

Water covered Earth
Slab ocean or prescribed SST
Considerations for idealized ocean models:

- Has everything the full GCM has.
- CAM4 is a lot cheaper than CAM5 or 6

The main differences between the different physics packages:

CAM4

↓

CAM5: prognostic aerosols, differences in shallow convection scheme and radiation

↓

CAM6: CLUBB replaces boundary layer turbulence, cloud macrophysics and shallow convection. Orographic blocking. More complicated microphysics
Considerations for idealized ocean models:
- Has everything the full GCM has.
- CAM4 is a lot cheaper than CAM5 or 6

The main differences between the different physics packages:
- CAM4
  - CAM5: prognostic aerosols, differences in shallow convection scheme and radiation
  - CAM6: CLUBB replaces boundary layer turbulence, cloud macrophysics and shallow convection. Orographic blocking. More complicated microphysics

CAM4 2deg FV = ~50 core hours/year
CAM6 2deg FV = ~300 core hours/year
Some miscellaneous things about experience with atmospheric simple models:

- Before embarking on the aquaplanet, Brian Medeiros sent out a questionnaire
  - 85 responses

- The biggest bottleneck = software engineering resources.
  - A large component of the work is a software engineering exercise and software engineers are already over-committed.
  - Resources are needed for that. We have had some supplemental NSF funding to contribute.
Thanks