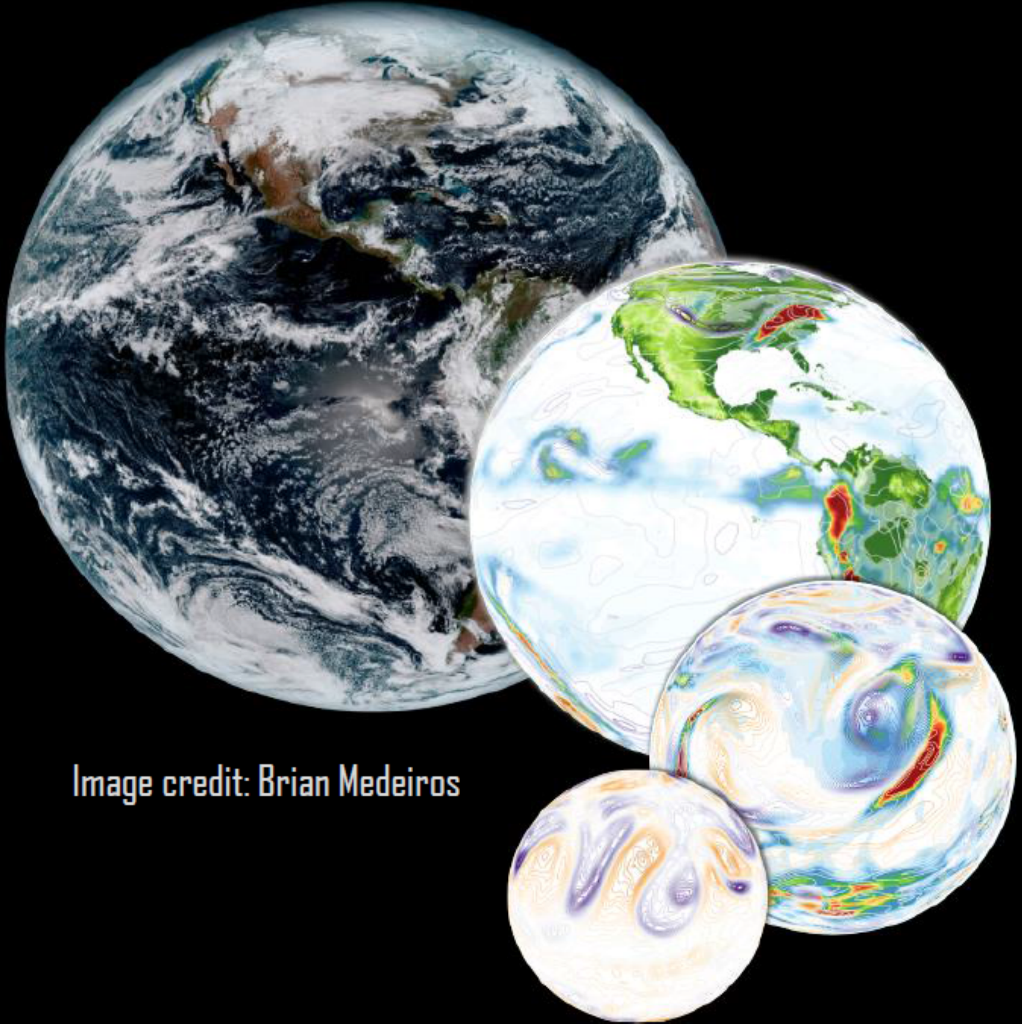

Image credit: Brian Medeiros

Simpler models in CESM

Isla Simpson
islas@ucar.edu

People (in alphabetical order): Jim Benedict, Amy Clement, Brian Eaton, Andrew Gettelman, Christiane Jablonowski, Jean-Francois Lamarque, Peter Lauritzen, Steve Goldhaber, Brian Medeiros, Lorenzo Polvani, Kevin Reed, Isla Simpson, Mariana Vertenstein, Colin Zarzycki

NCAR

NSF

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Atmospheric → Simpler models in CESM

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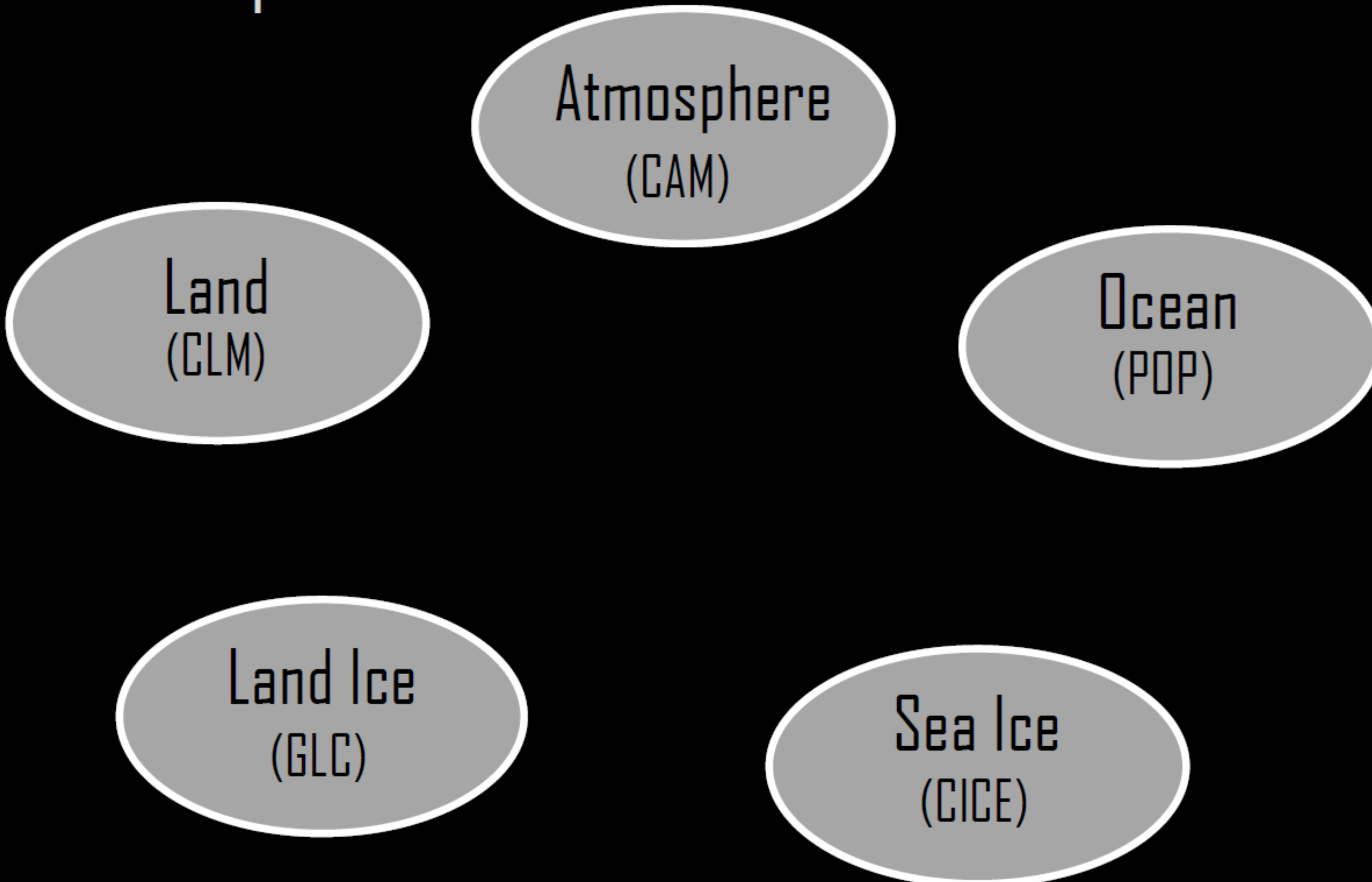

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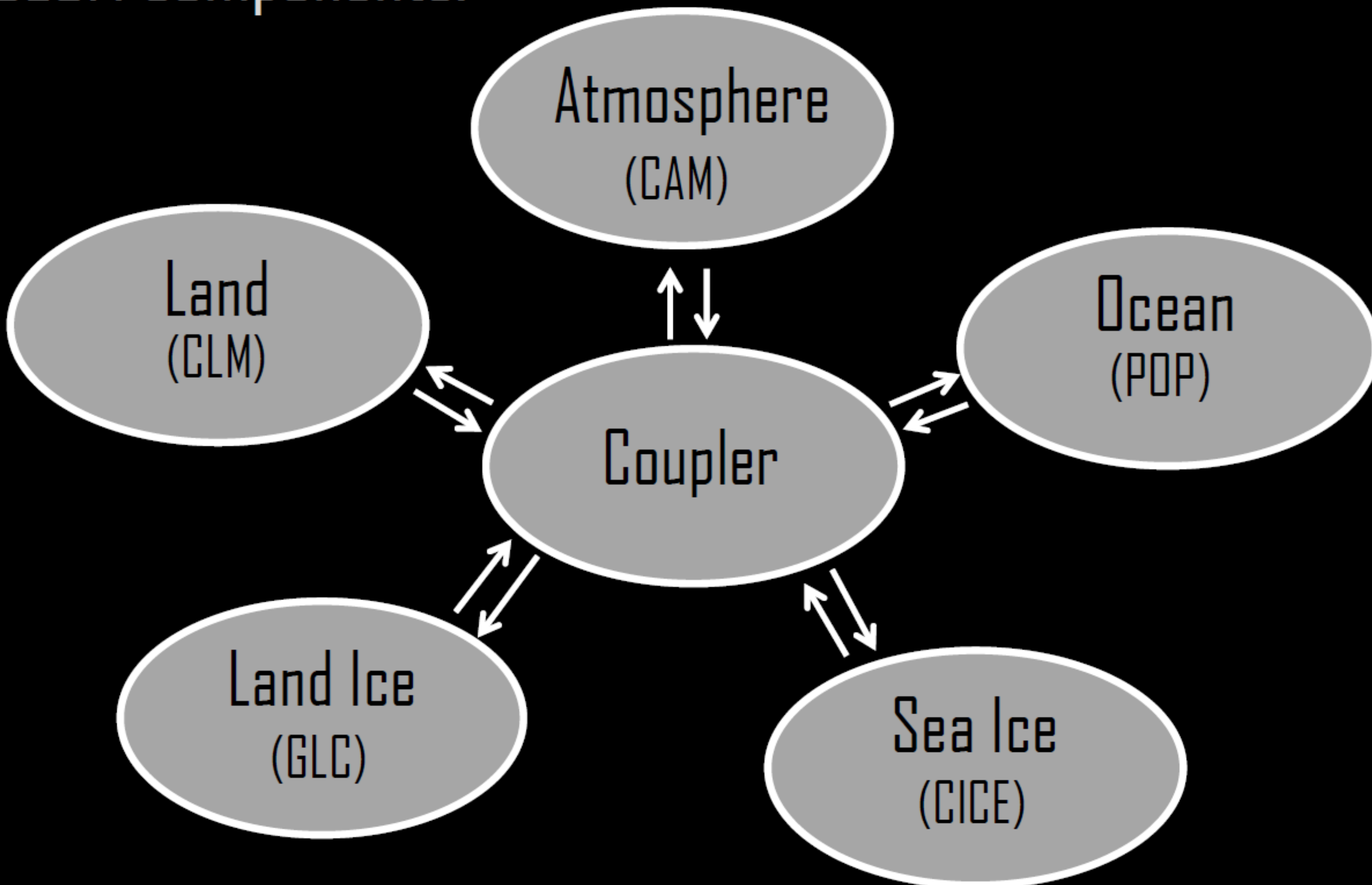

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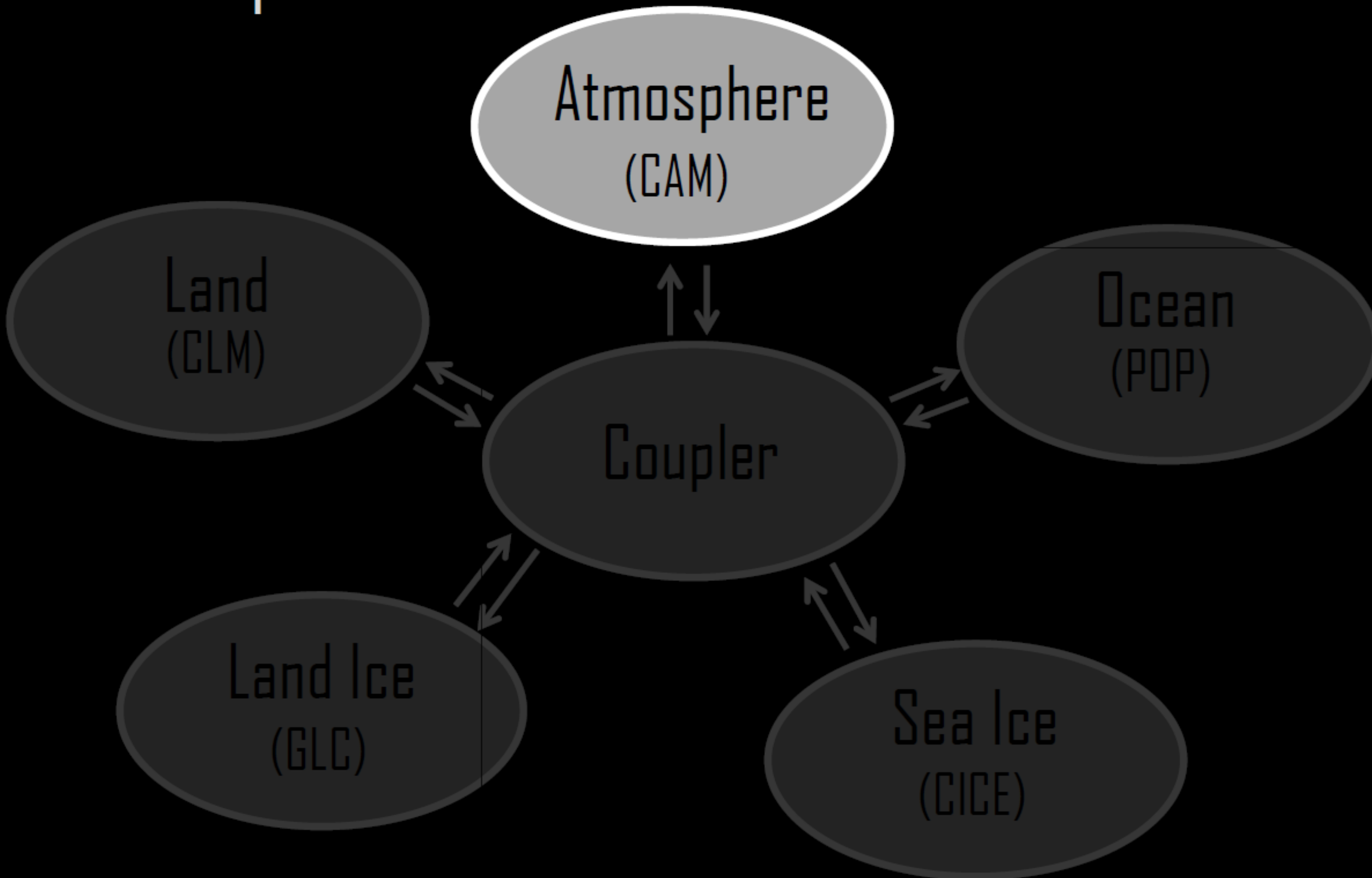

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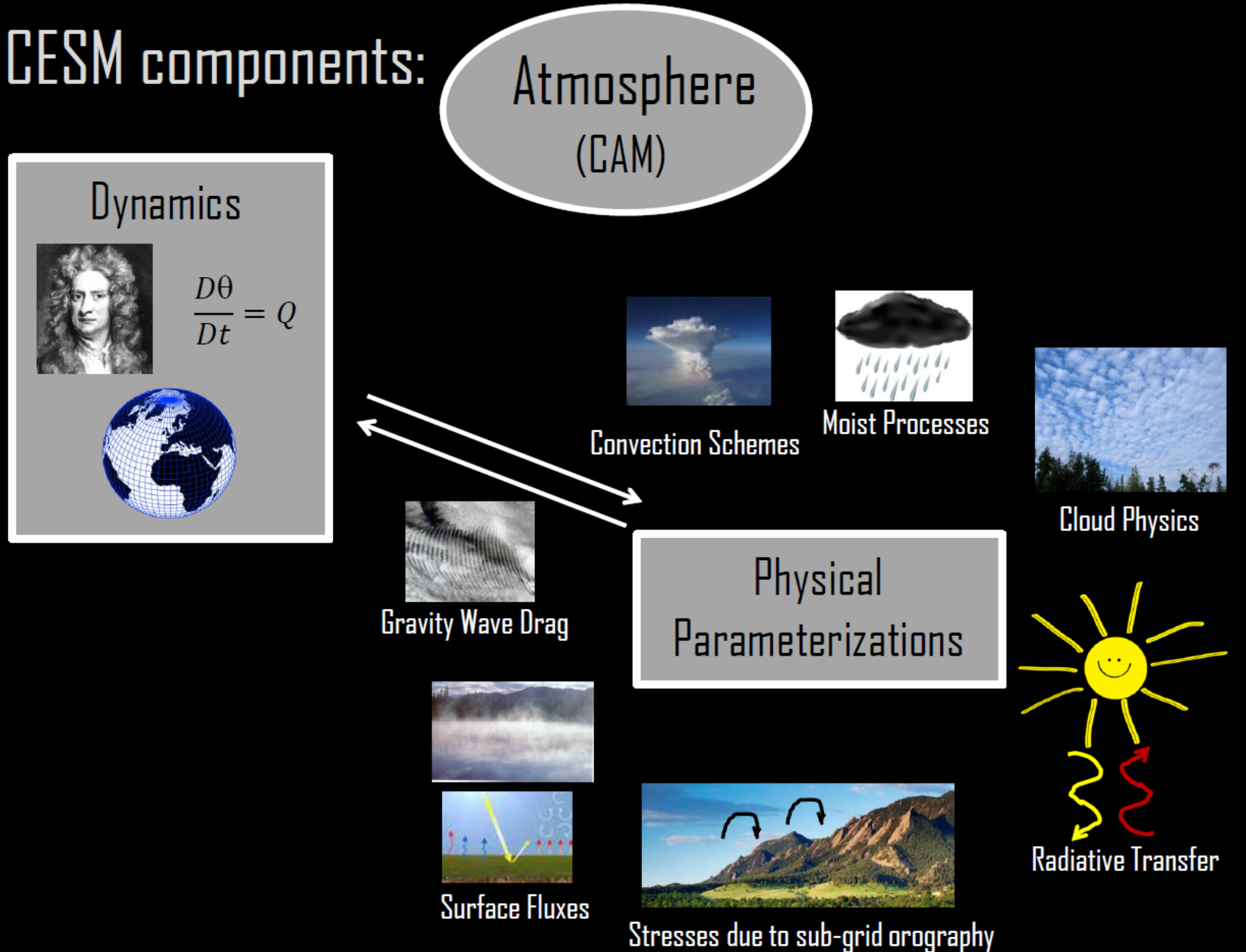
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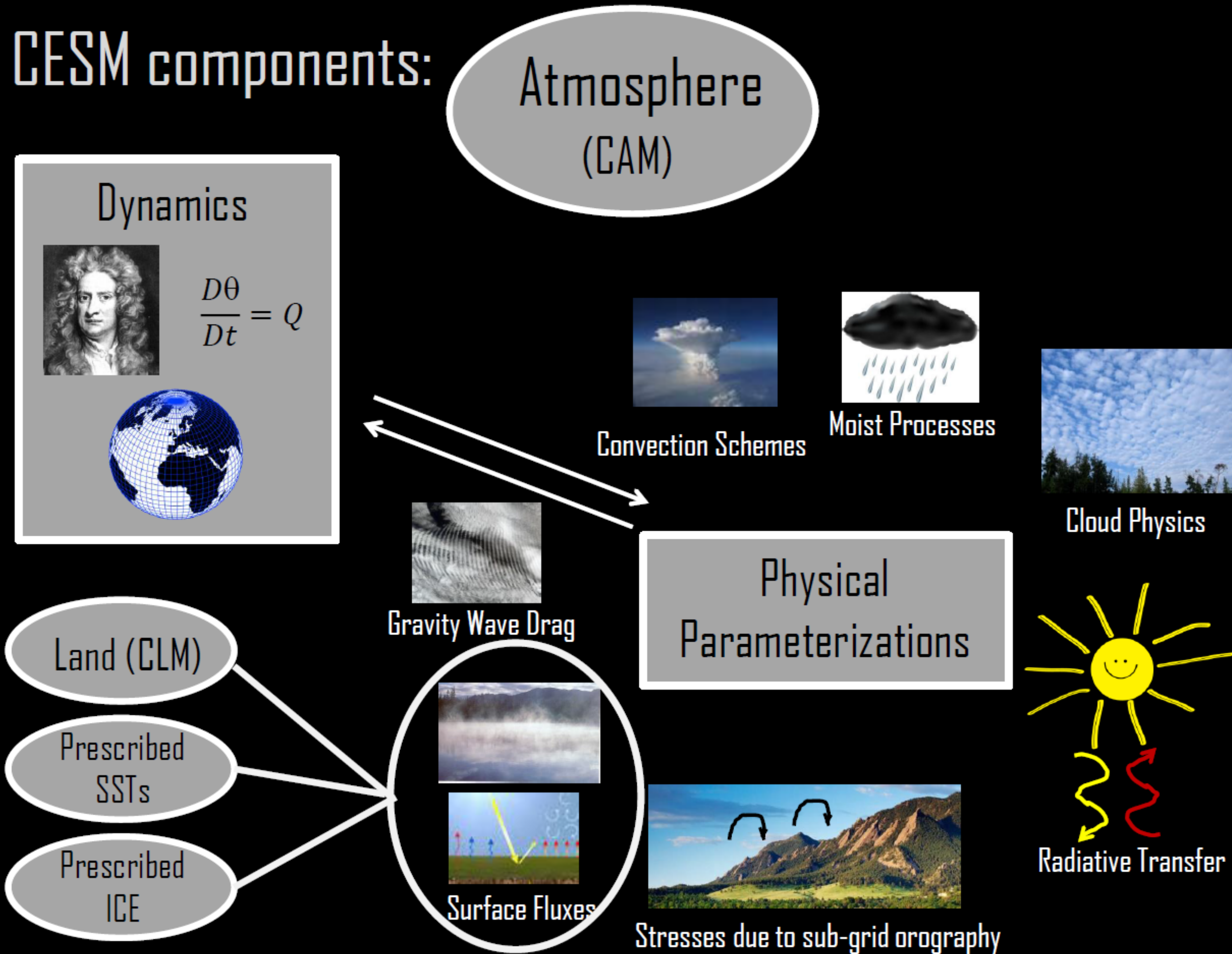

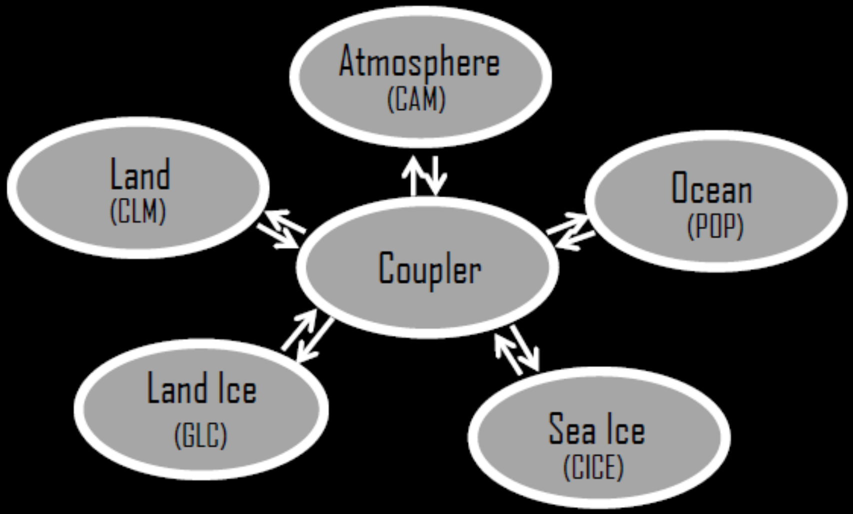
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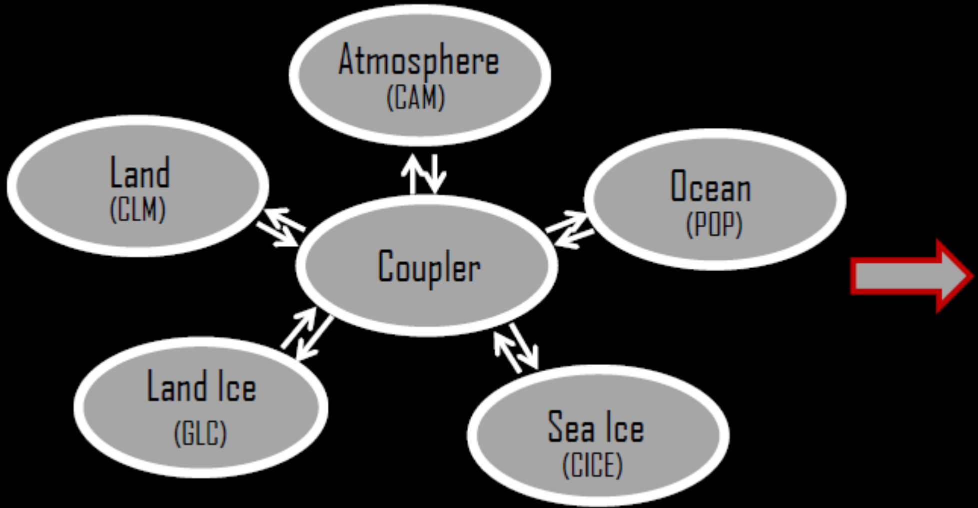
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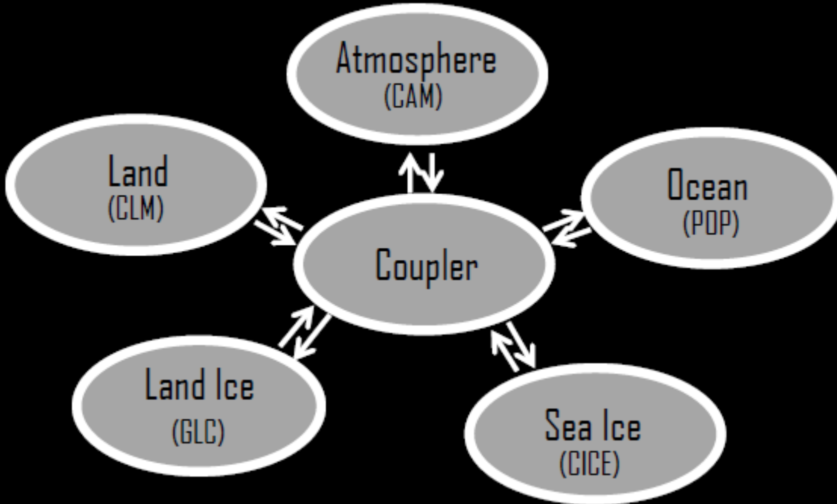
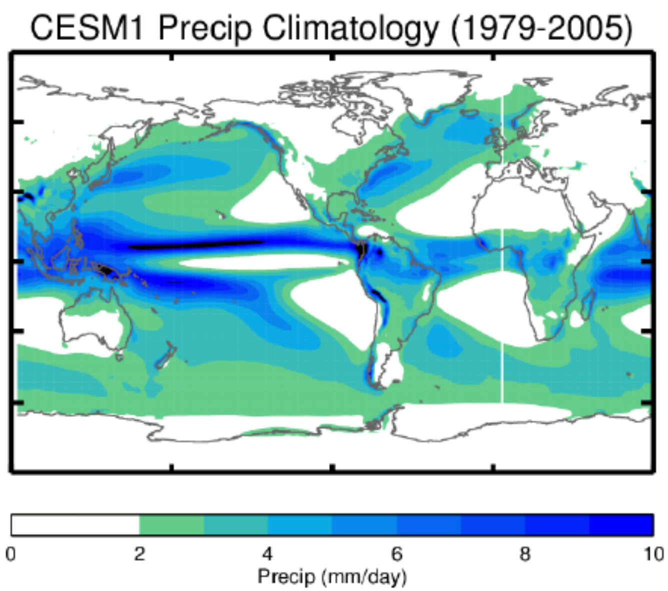
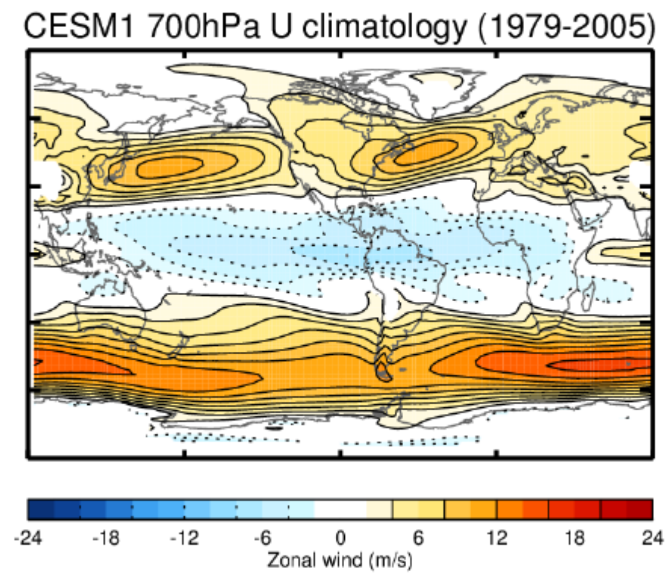
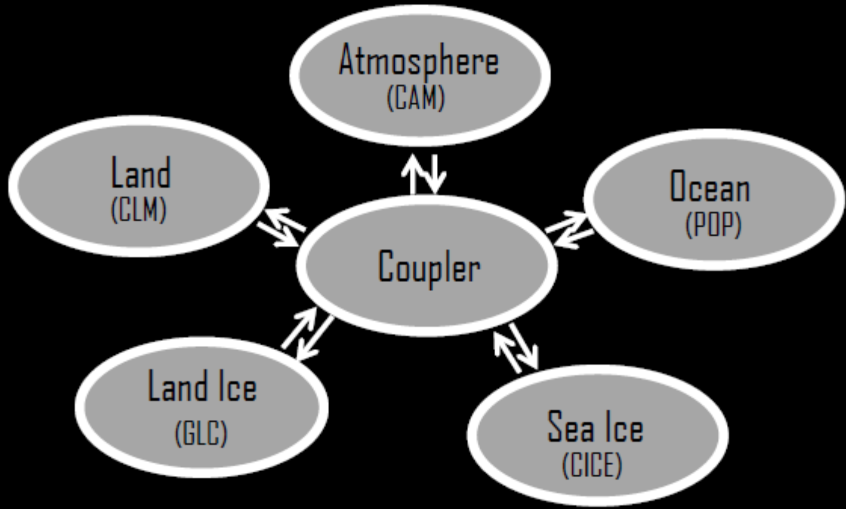


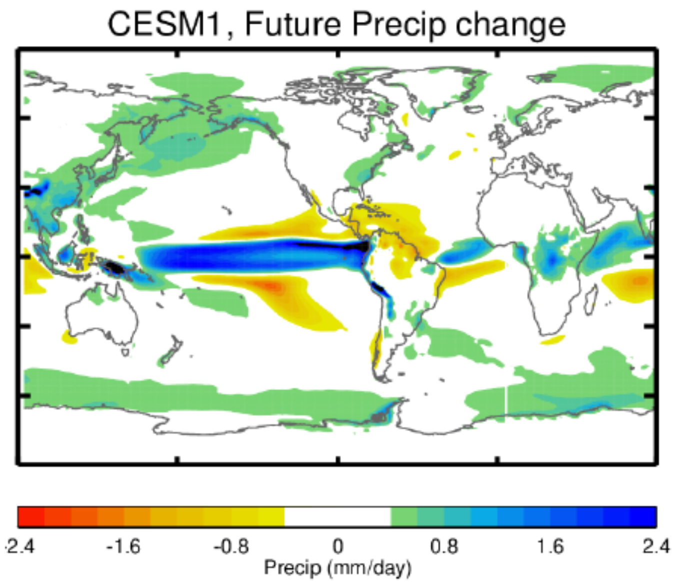
Present day, annual mean climatologies as simulated by CESM

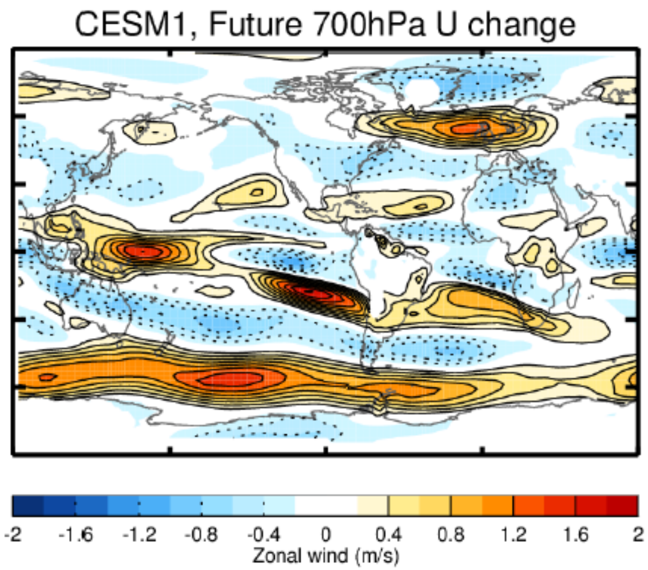


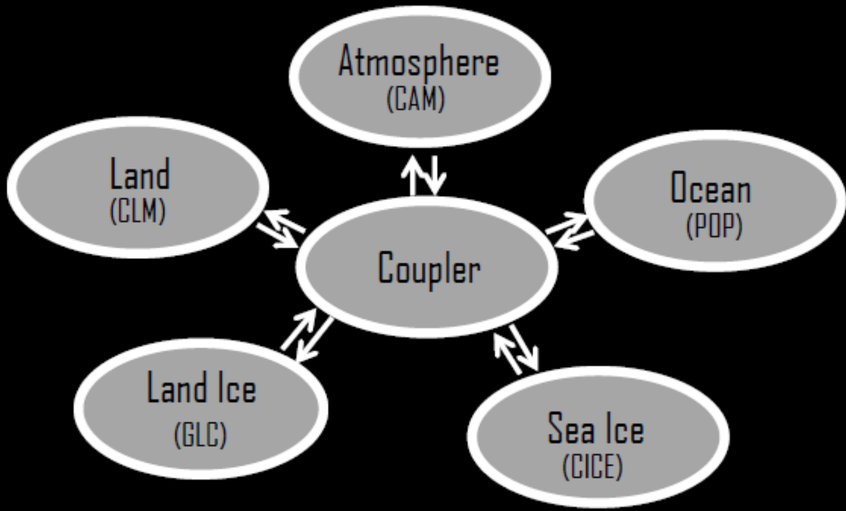




(2070-2099) – (1979-2005) changes as simulated by CESM under RCP8.5







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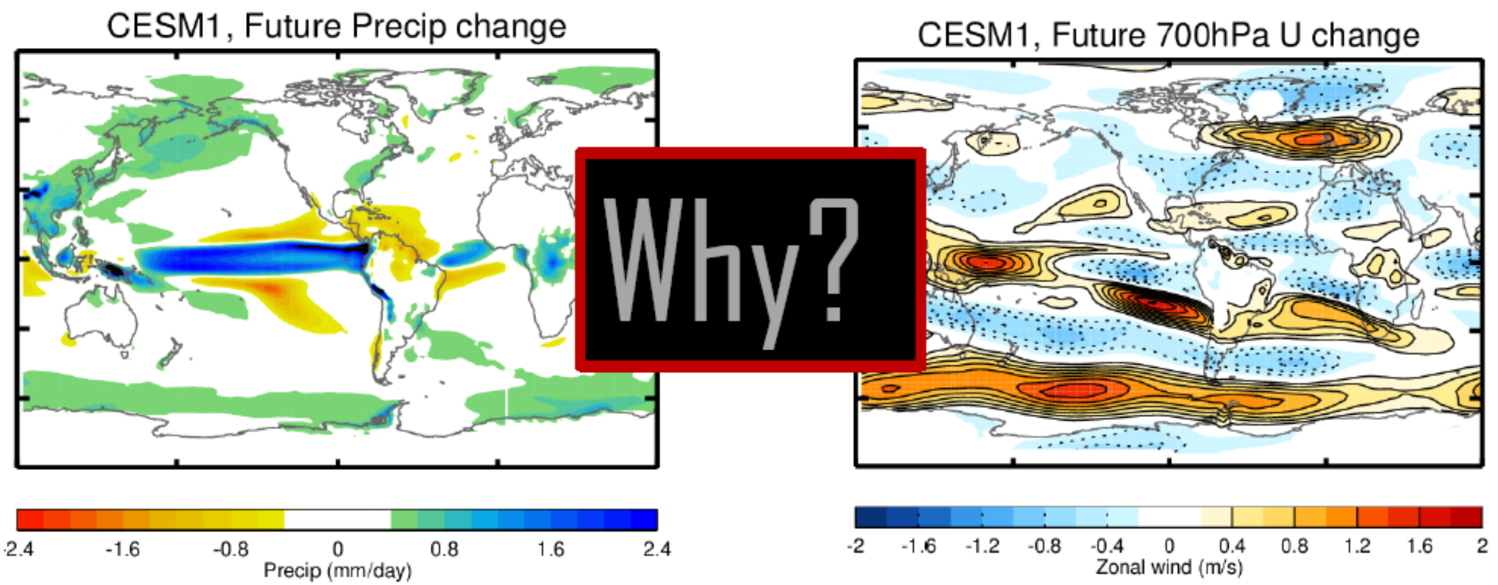

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- To obtain this climate, we needed to use this…

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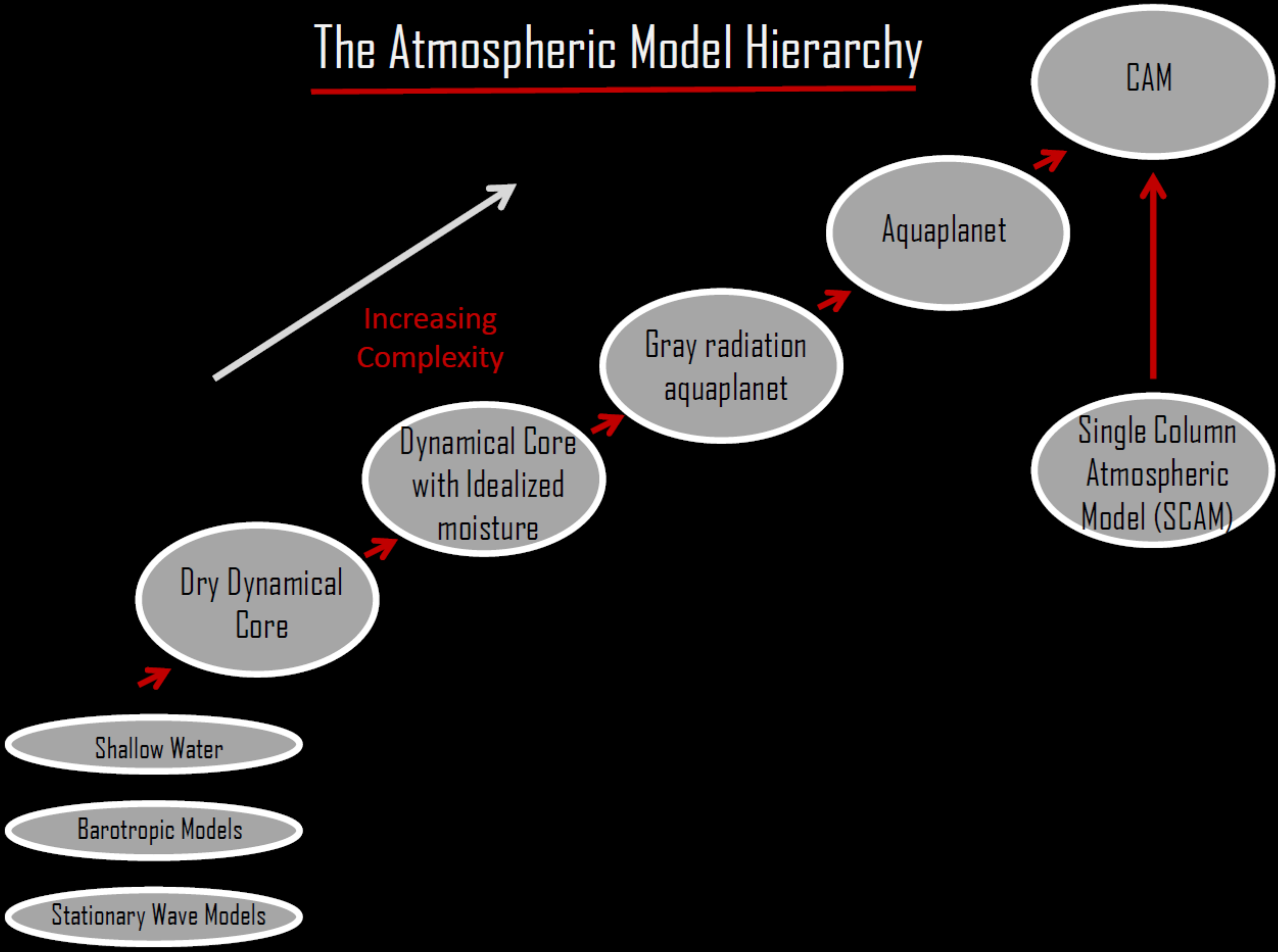
Advice:

- Always keep your eye on the real world/full CESM
- Use the model hierarchy
- Know your model's limitations

The Atmospheric Model Hierarchy



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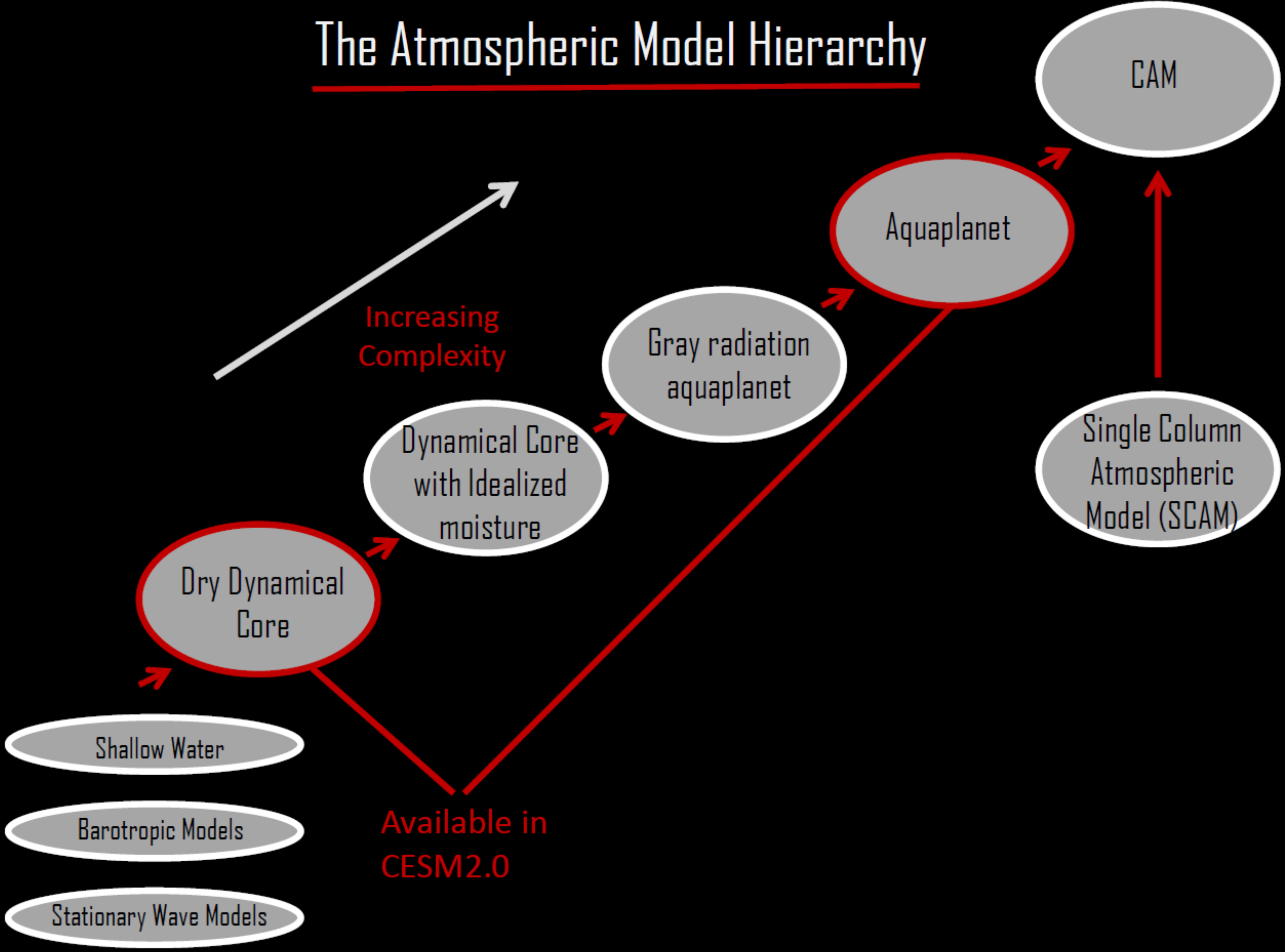

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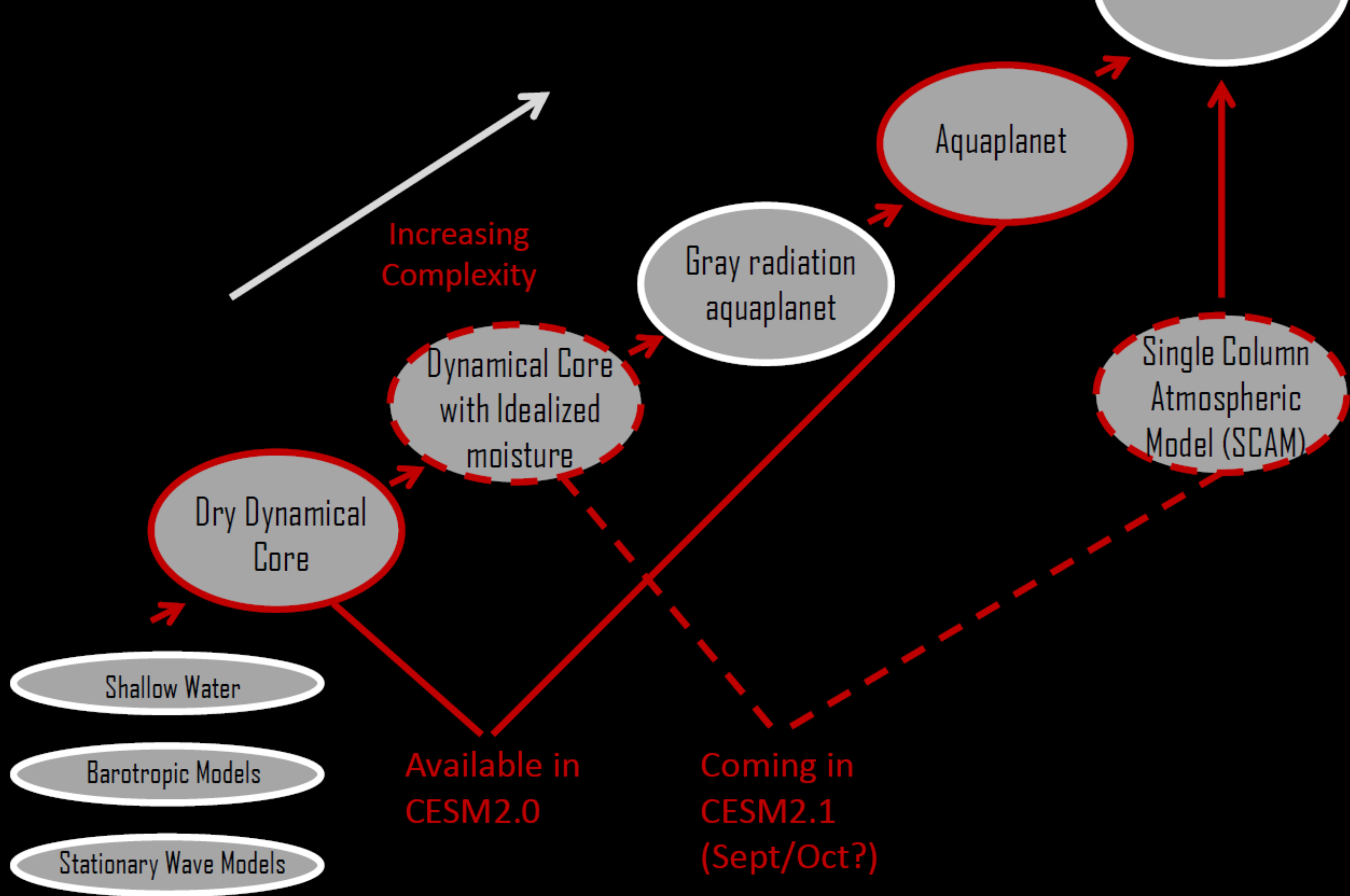

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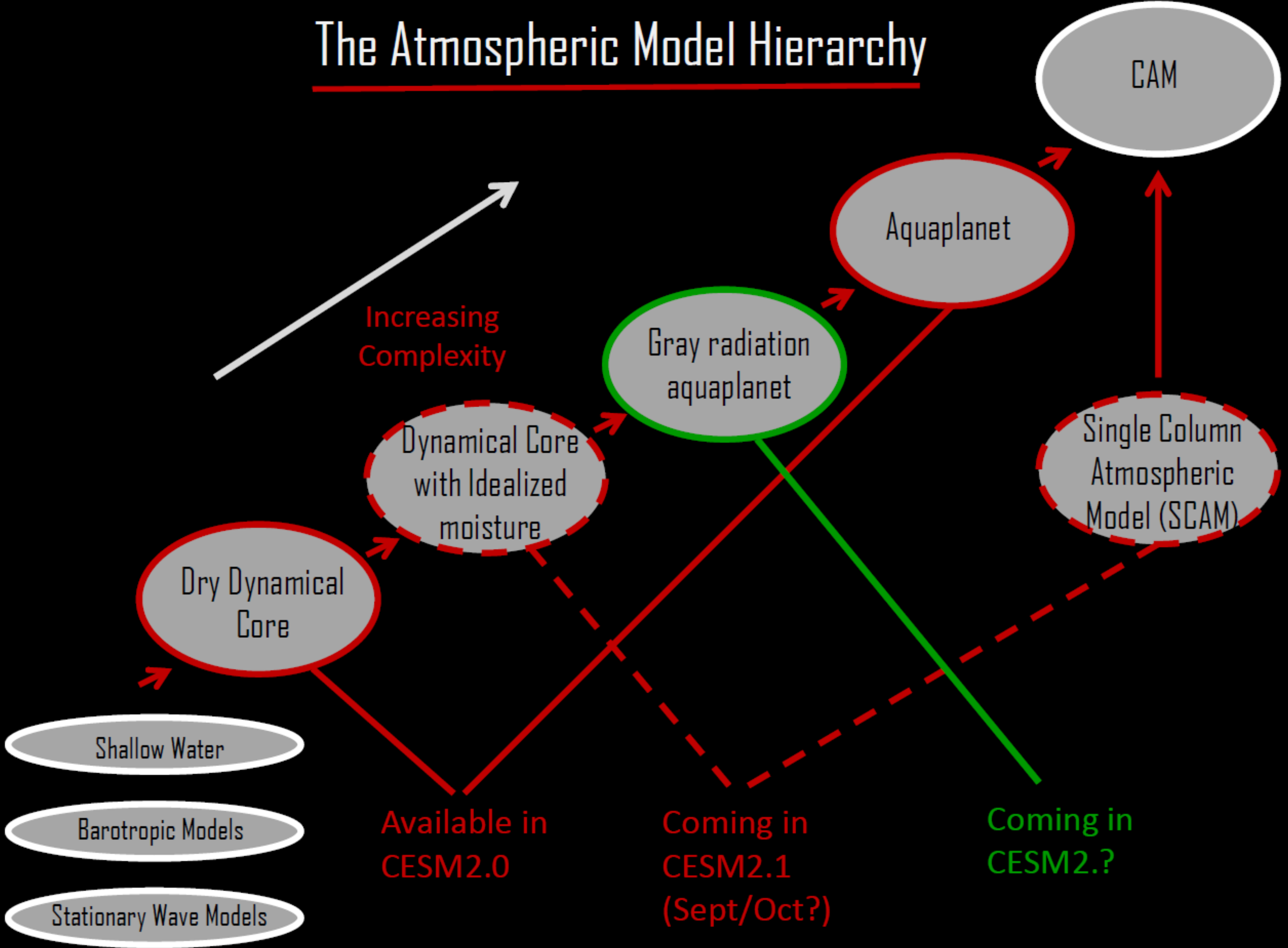

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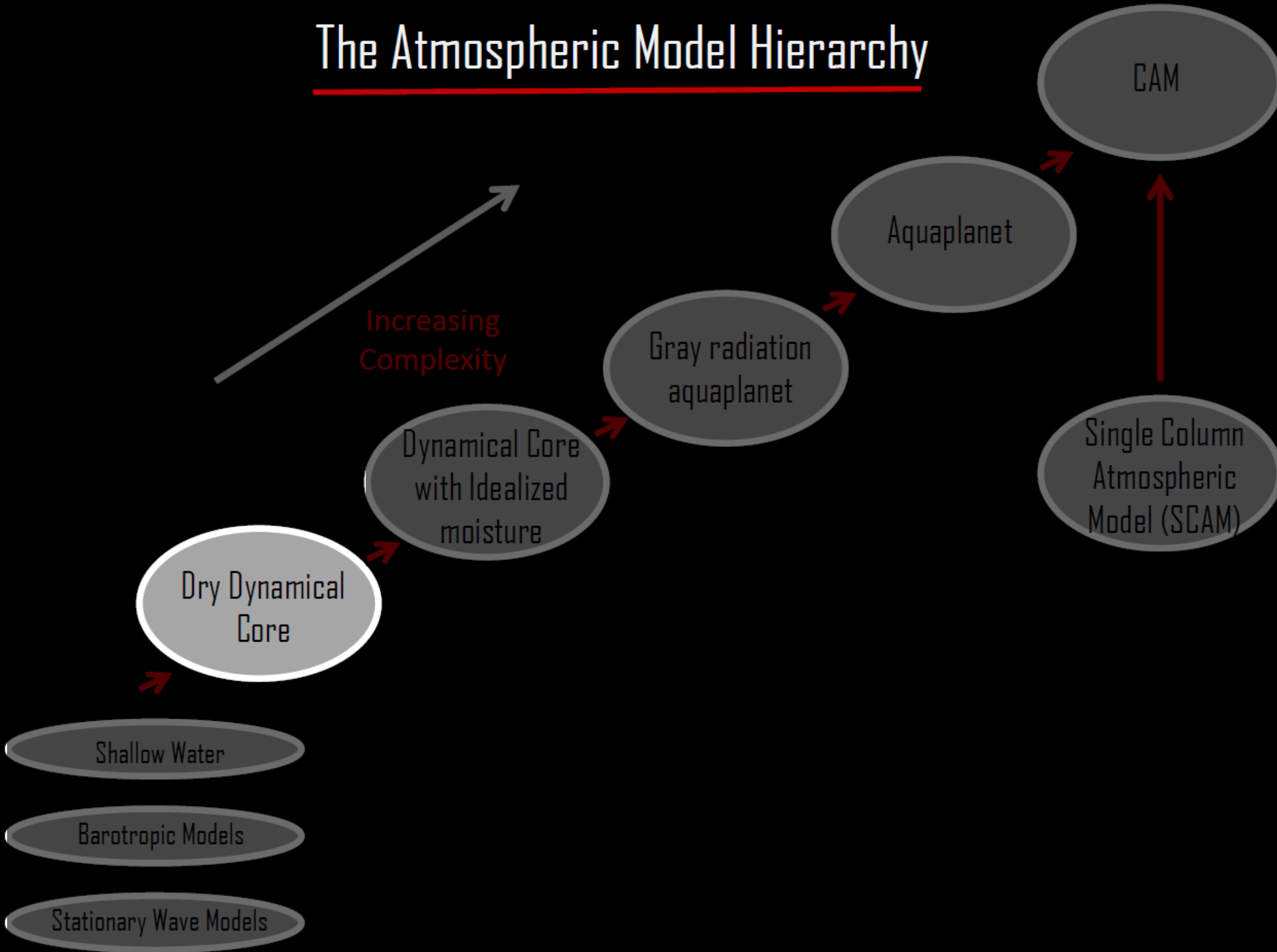

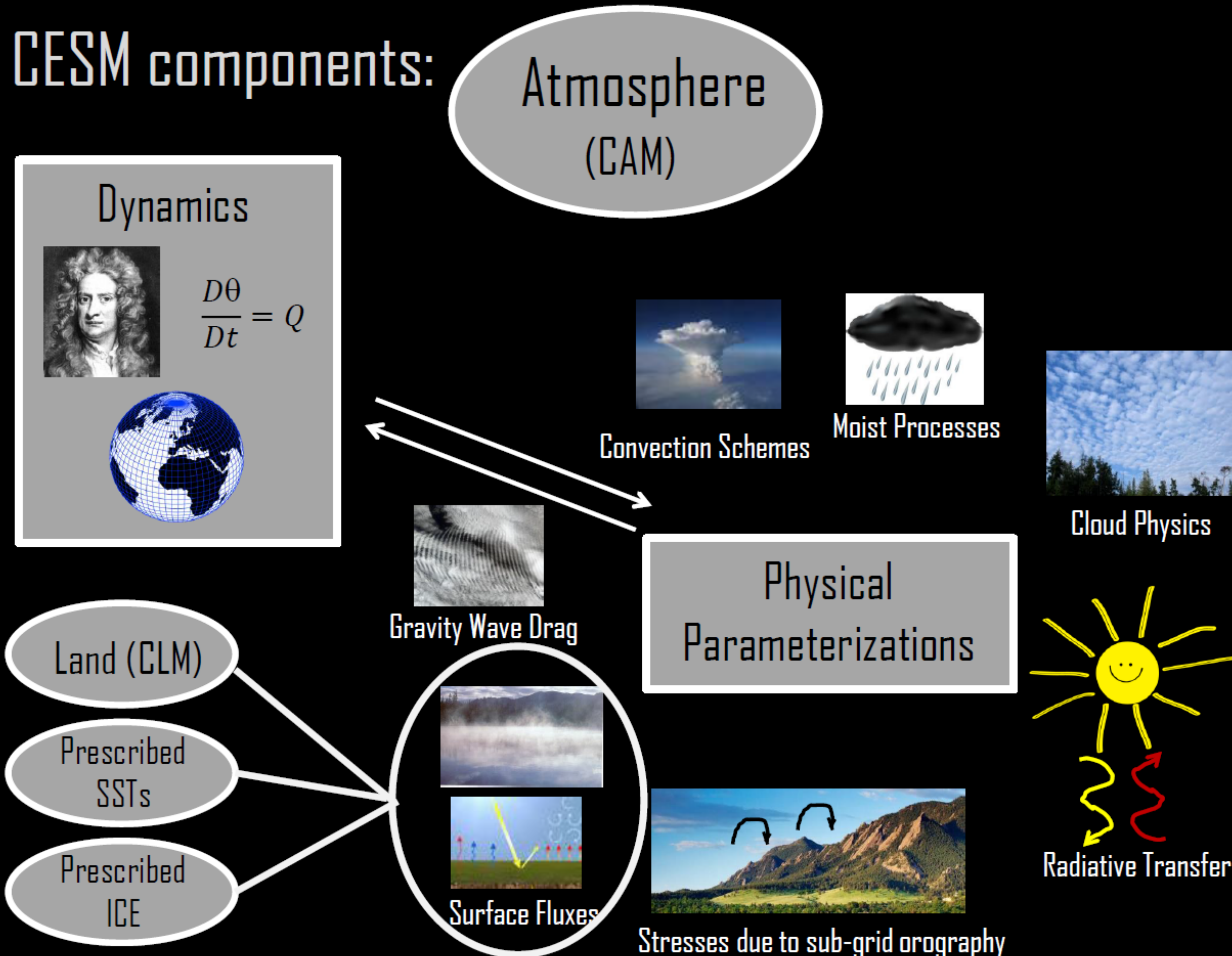

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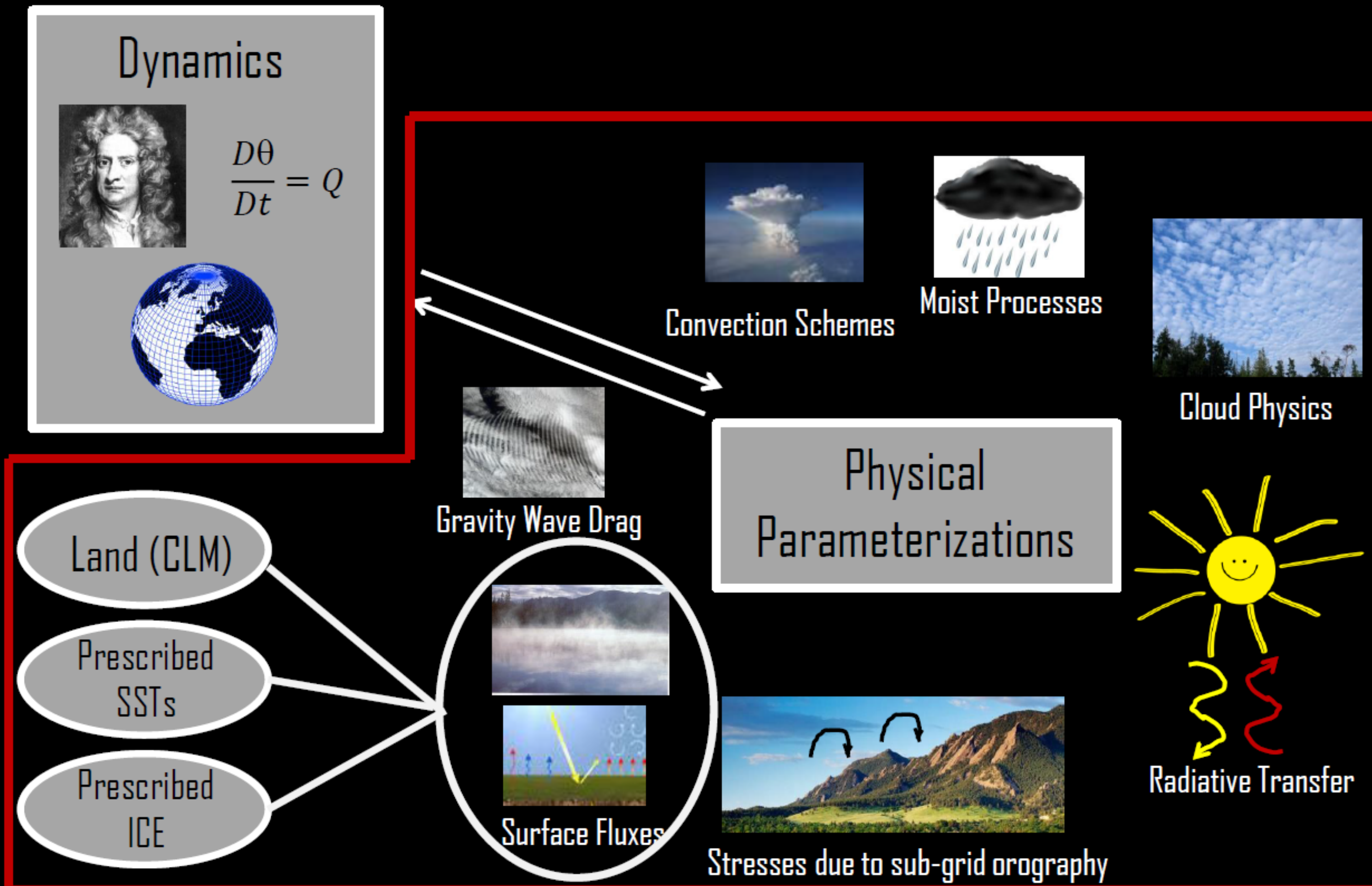
The Dry Dynamical Core



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

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

The Held-Suarez Configuration

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**

Compset = FHS94

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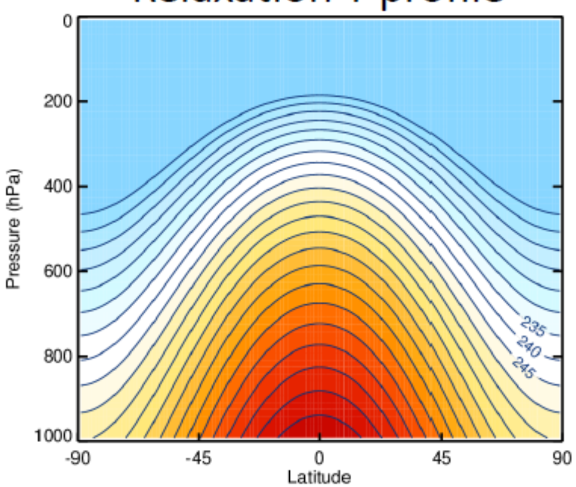

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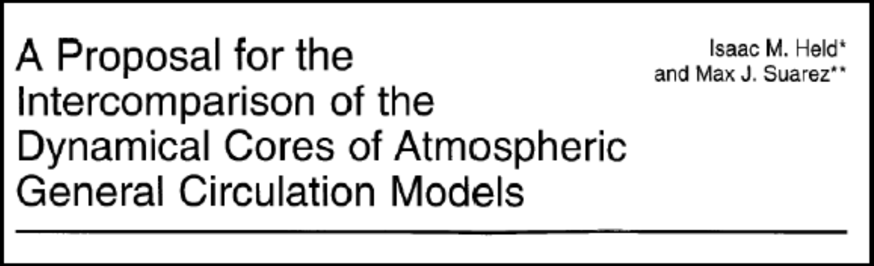
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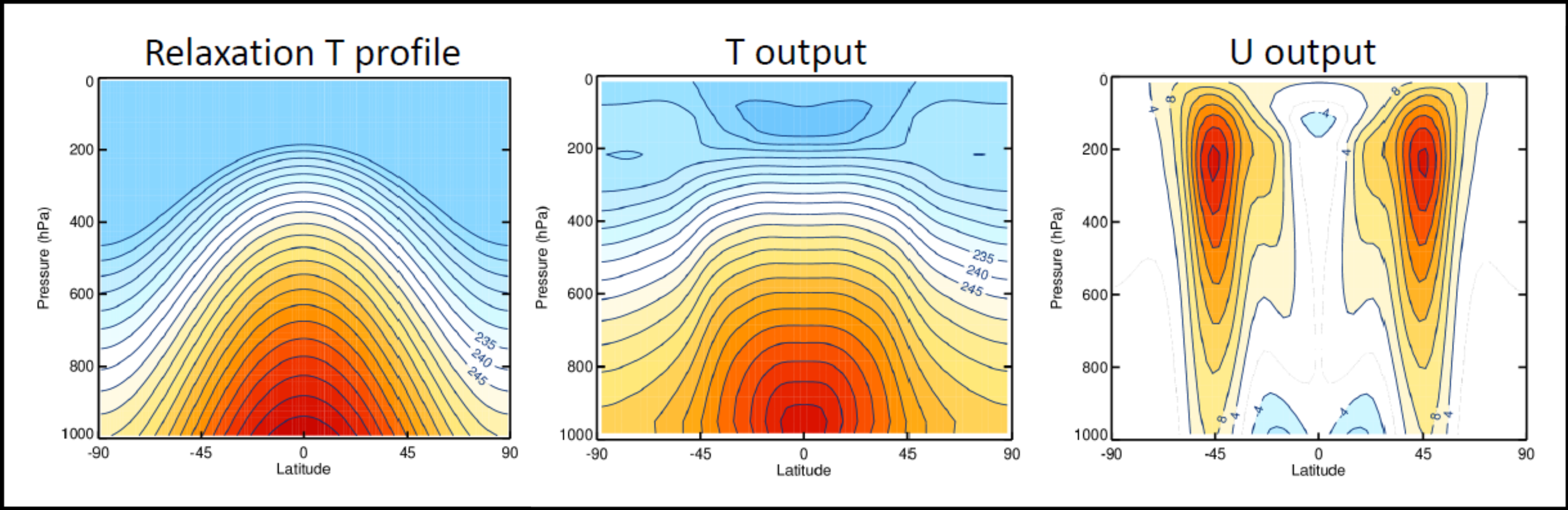
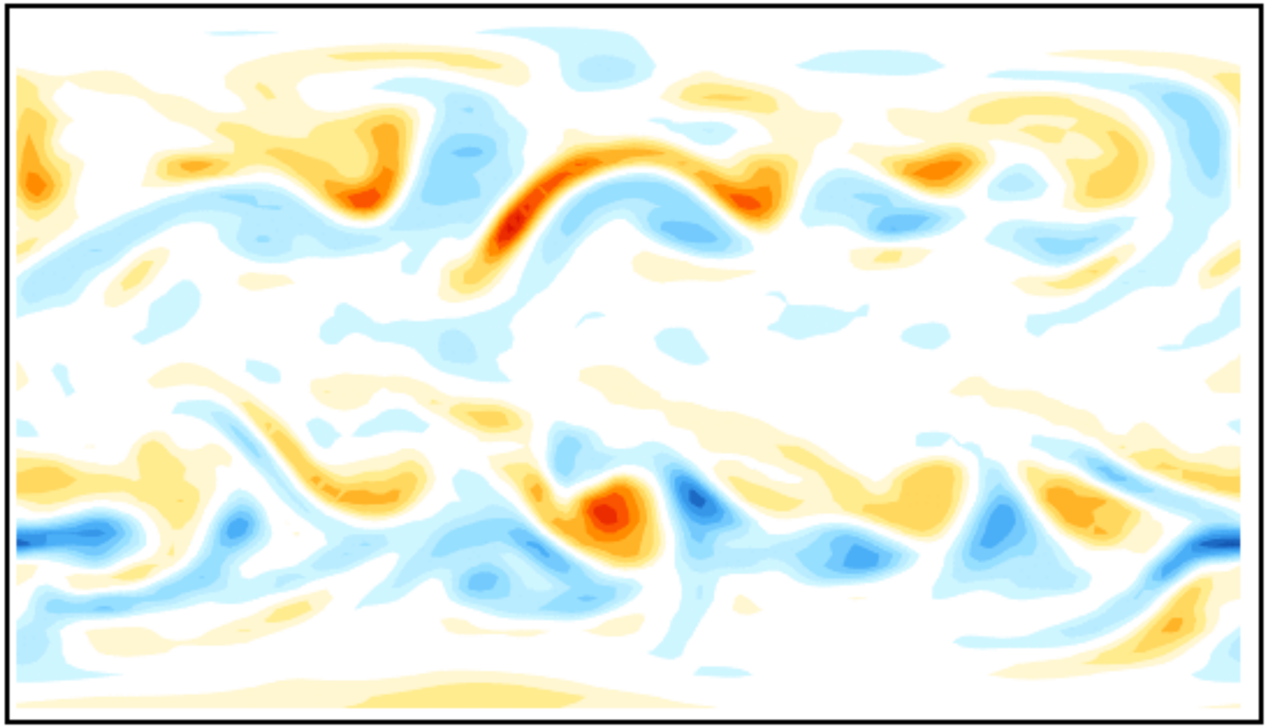


The Held-Suarez Configuration

500hPa Vorticity in a Held-Suarez simulation



Step 1:Set up the Held-Suarez case

A Held-Suarez simulation can be set up e.g., for the T42 resolution, by executing the following command from the $CESM/cime/scripts directory

```
./create_newcase -case $CASEDIR -compset FHS94 -res T42_T42 -mach $MACH -confopts _Ld1200
```

where the case directory ($CASEDIR) and machine ($MACH) are specified by the user e.g., when using yellowstone, $MACH = yellowstone. In order to run the T85L30 or T85L60 resolutions, T42_T42 can simply be replaced by T85_T85 or T85z60_T85 in the above command.

Step 2:Configure the Held-Suarez Case

The configure option "_Ld1200" in the command above ensures that the model runs for 1200 days. This could alternatively be set up from within $CASEDIR using the following command

./xmlchange STOP_OPTION=ndays,STOP_N=1200

Depending on how the job queue's are set up on the machine being used, it may be necessary to divide the simulation up into separate parts, especially for the higher resolution case. As an example, to run the simulation in four separate chunks of length 300 days, execute the following xml command from within $CASEDIR

```
./xmlchange STOP_OPTION=ndays,STOP_N=300,RESUBMIT=3
```

Step 3:Set-up and Build the Case

Set up and build the case by invoking the following commands from within $CASEDIR

```
./case.setup
```

```
./case.build
```

Step 4:Run the Case

```
./case.submit
```

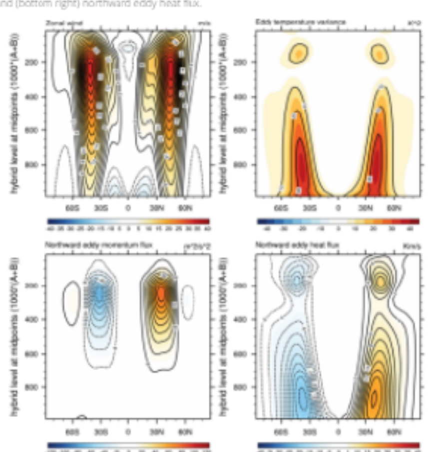
See the CESM users guide for more information on these procedures.

Step 5:Validate the model output

By default, both monthly and 6 hourly instantaneous fields are output from the simulation. The monthly history files contain a number of standard fields and of note is that here the variable QRS is the temperature tendency associated with the relaxation toward the equilibrium temperature profile. There is also a non-zero temperature tendency associated with horizontal diffusion (DTH). This temperature tendency includes frictional heating rates associated with the kinetic energy dissipation by horizontal diffusion of momentum as well as a correction that accounts for the fact that horizontal diffusion is being applied on model levels, not pressure levels (see CAM5 documentation, section 3.3.17).

The 6 hourly instantaneous fields consist of zonal and meridional wind (U and V) and temperature (T). This NCL script can be used to produce the following plots from days 200 to 1200 of the simulation, using the 6 hourly instantaneous fields. It is recommended that new users ensure that similar results are obtained with their set up i.e., westerly jets in each hemisphere with similar magnitudes to those below, along with comparable eddy temperature variance and northward eddy momentum and heat fluxes. Note that one may expect small deviations from these results due to a different sampling of the natural variability that is inherent to the model.

Figure 1: Zonal mean outputs for days 200 to 1200 of a simulation run using the FHS94 compset at T42L30 resolution. (Top left) zonal wind, (top right) eddy temperature variance, (bottom left) northward eddy momentum flux and (bottom right) northward eddy heat flux.



http://www.cesm.ucar.edu/models/simpler-models/held-suarez.html

Step-by-step instructions

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

Instructions on:

Running with a different dynamical core

Running with different horizontal/vertical resolutions

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 Dry Dynamical Core

Example uses:

- Tropospheric response to stratospheric cooling (ozone hole like)

  Kushner and Polvani (2004)

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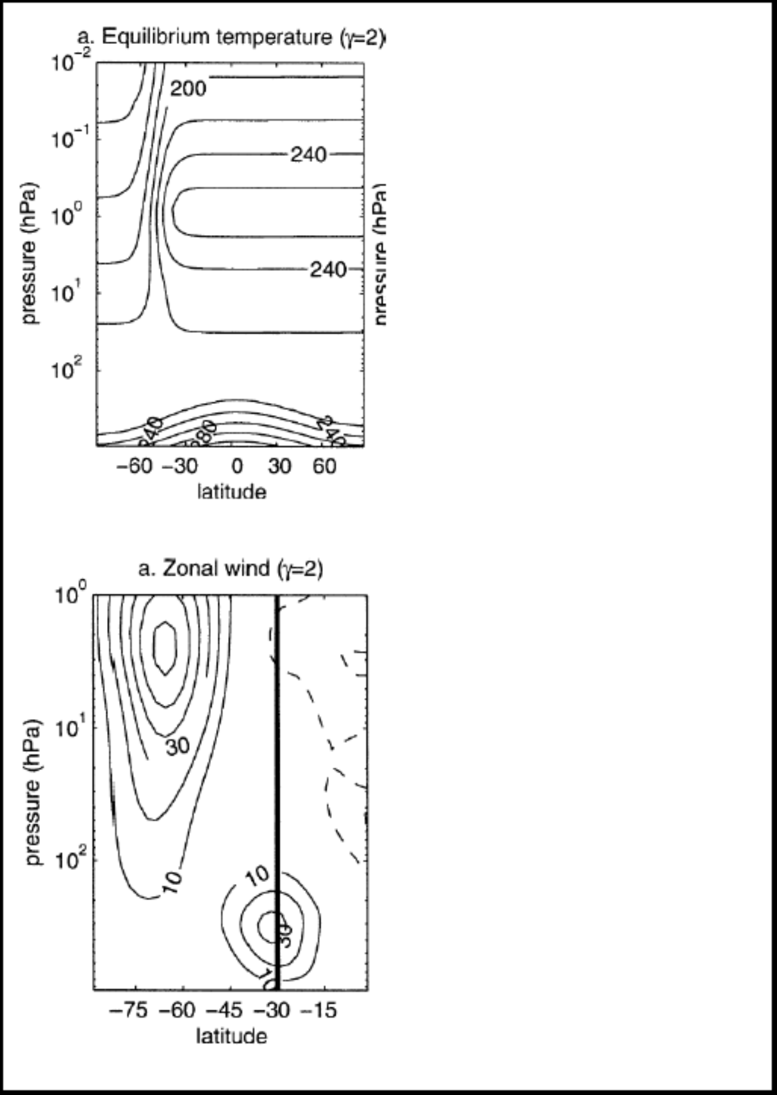

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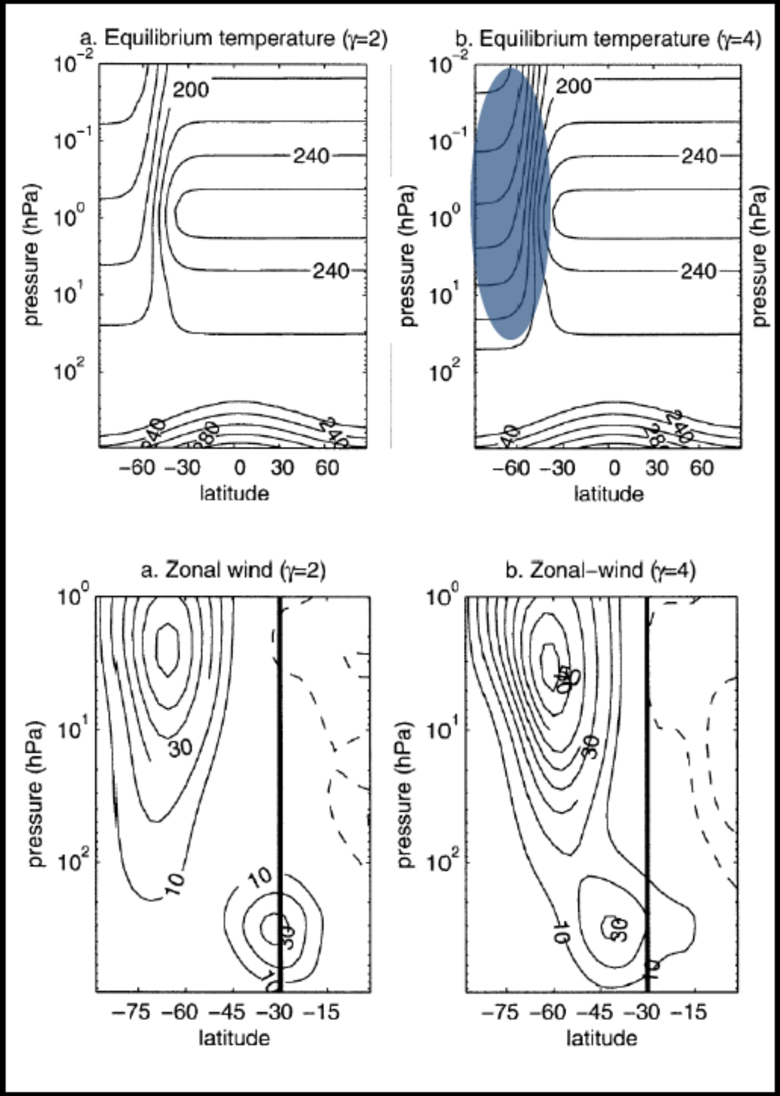

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Good for:

- 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

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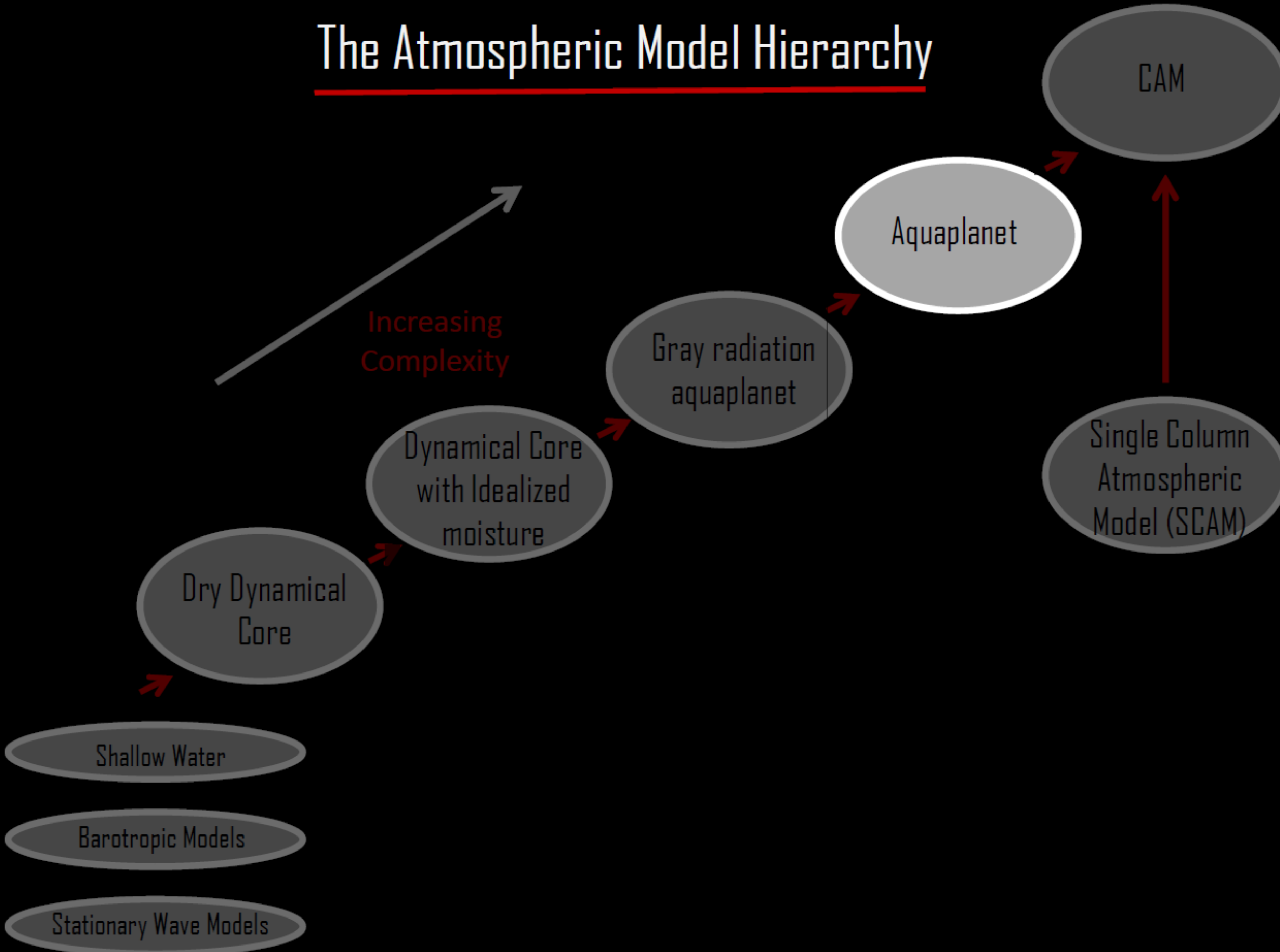
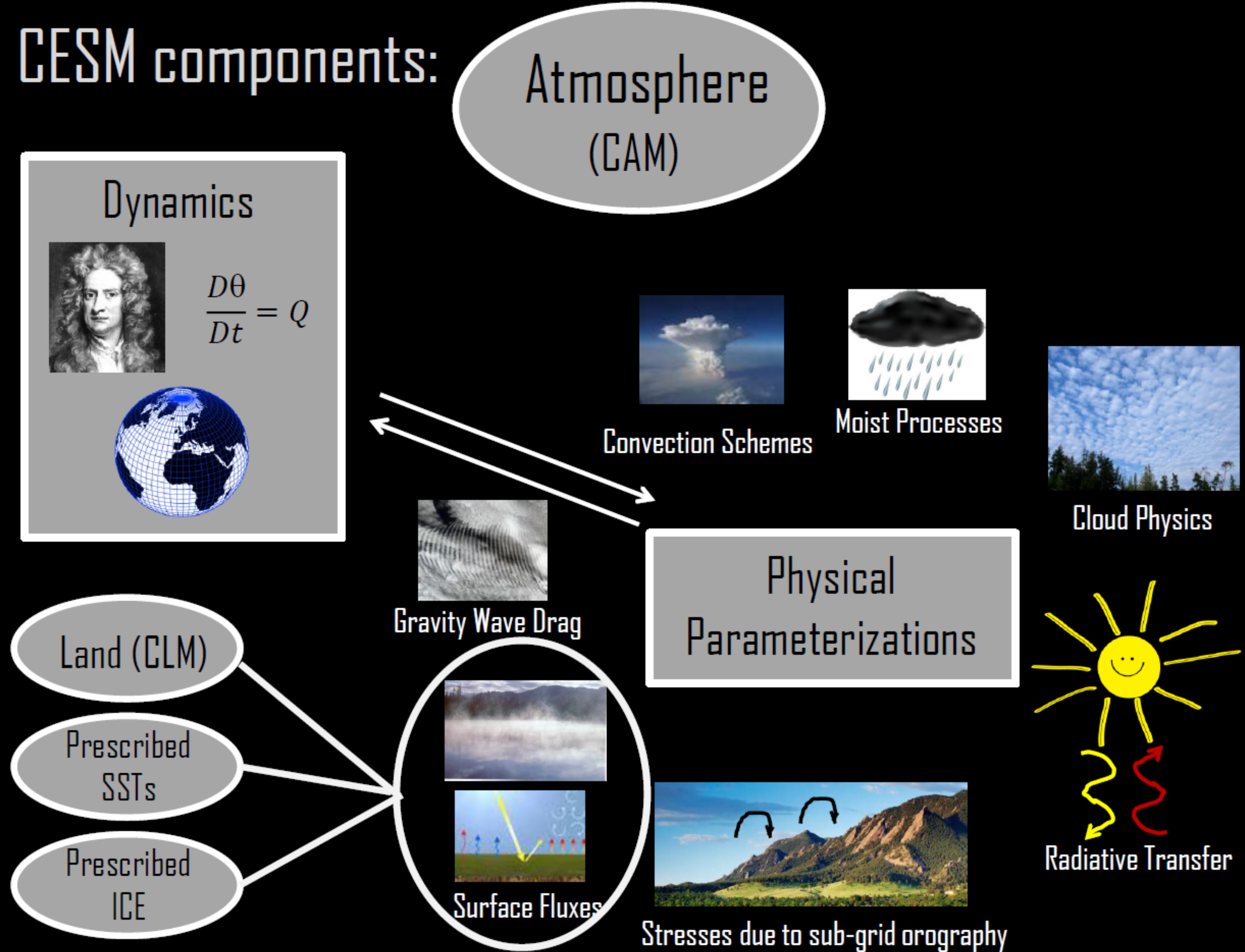
The Atmospheric Model Hierarchy

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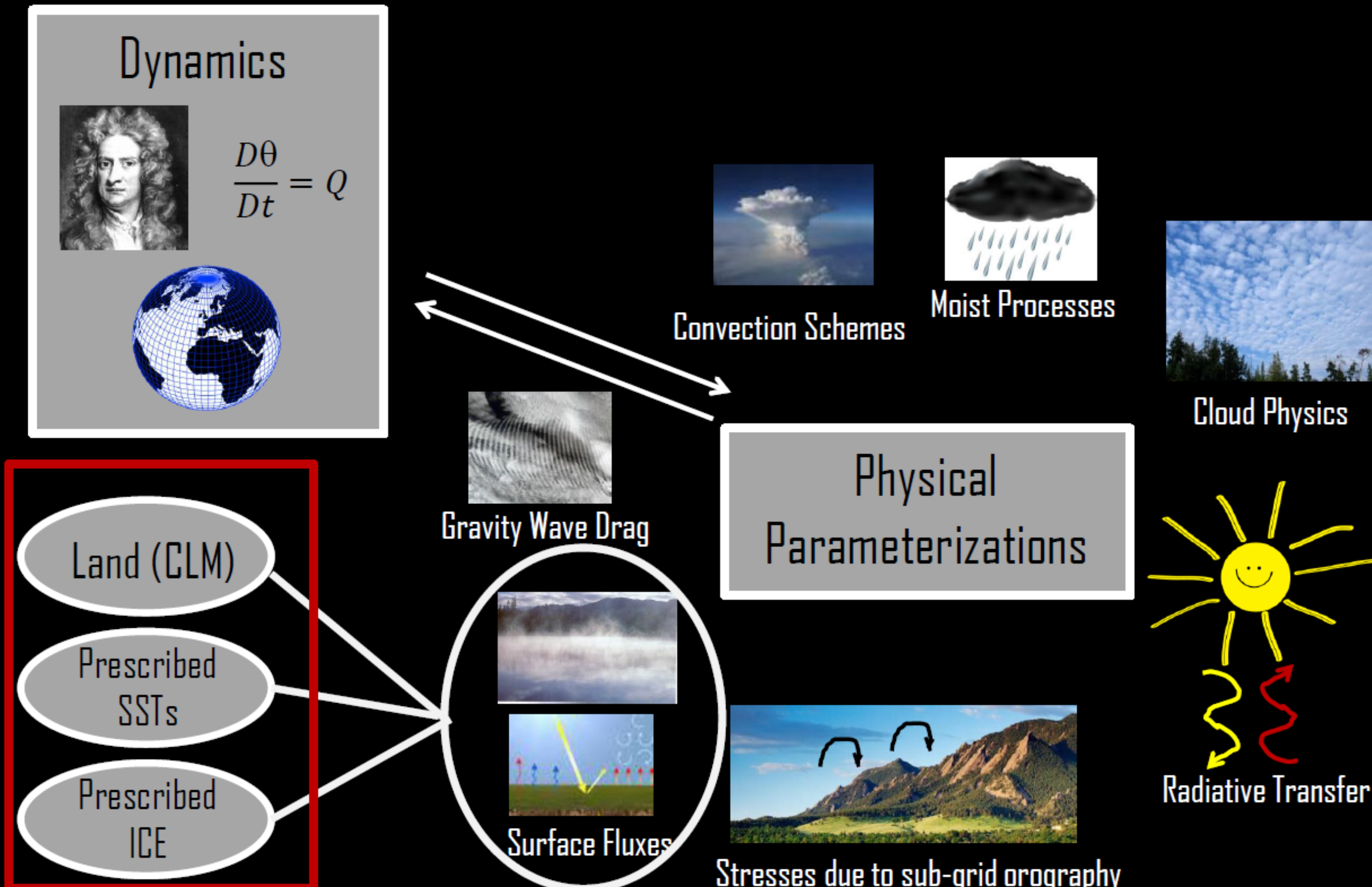
The Aquaplanet



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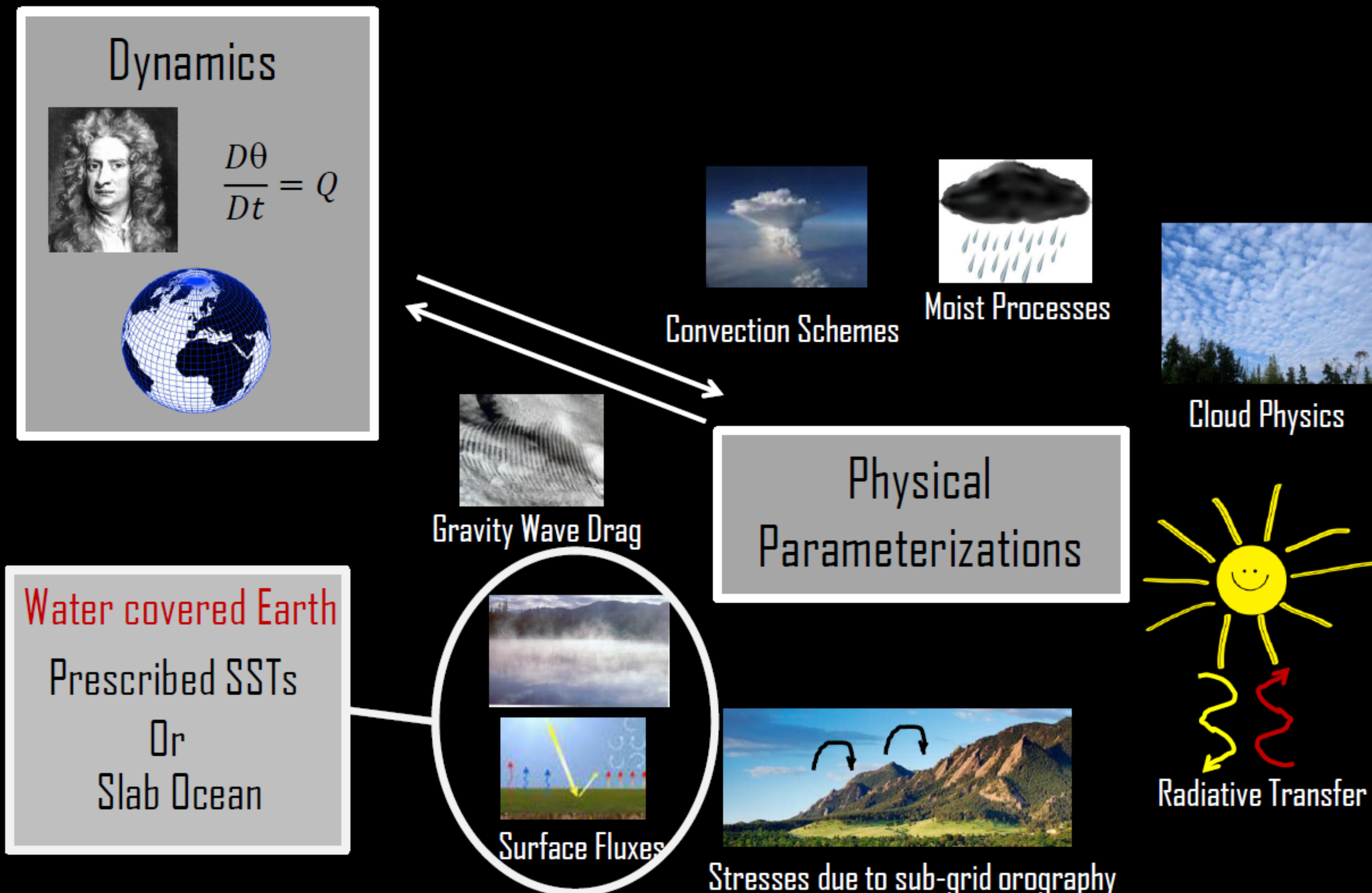

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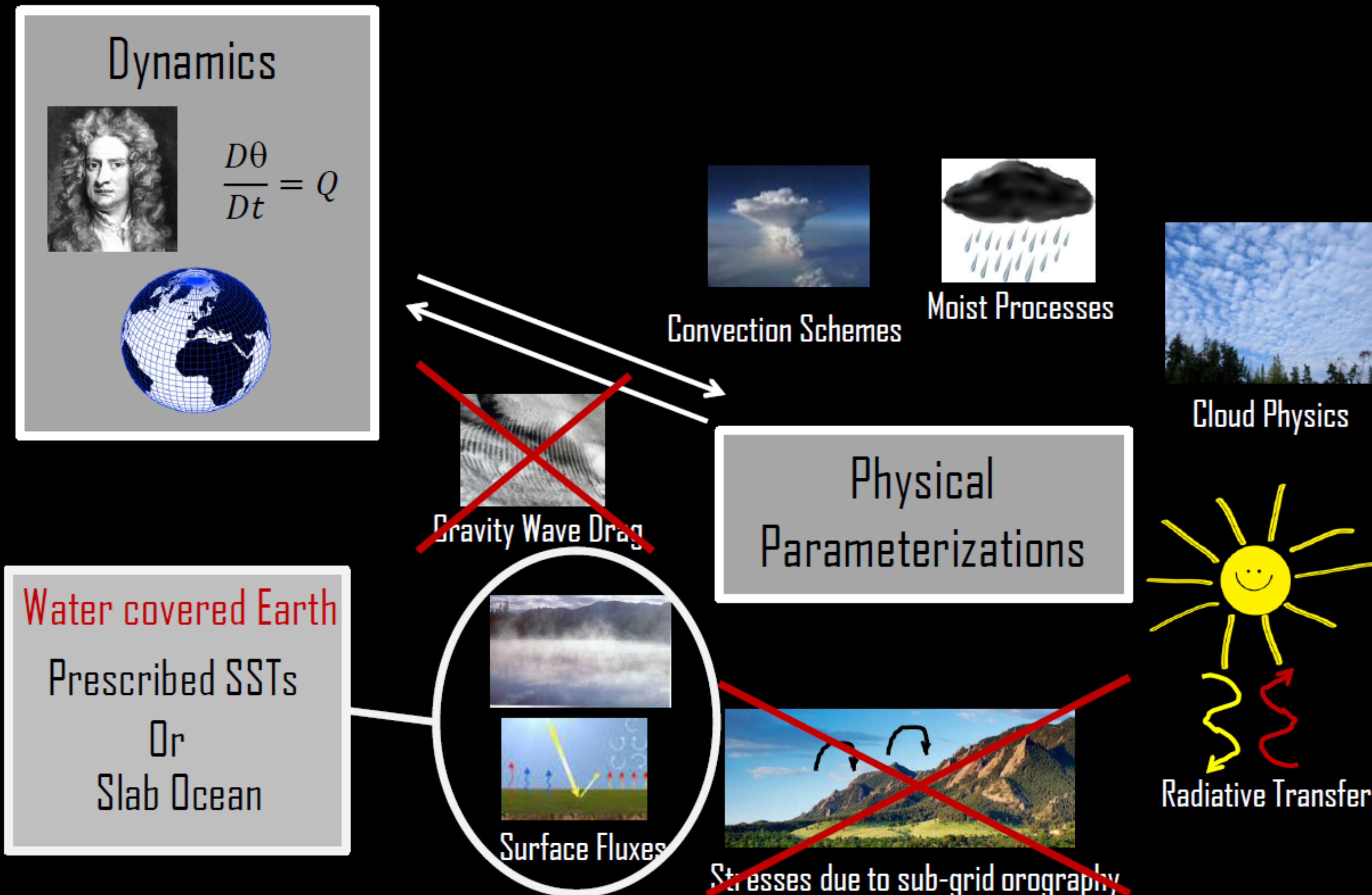


AGU PUBLICATIONS

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE

10.1002/2015MS000593

Reference aquaplanet climate in the Community Atmosphere Model, Version 5

Brian Medeiros[1], David L. Williamson[1], and Jerry G. Olson[1]

Available out of the box with CAM4, CAM5 and CAM6 physics

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

Prepetual Equinox with seasonal cycle capabilities

Prescribed SSTs or Slab Ocean

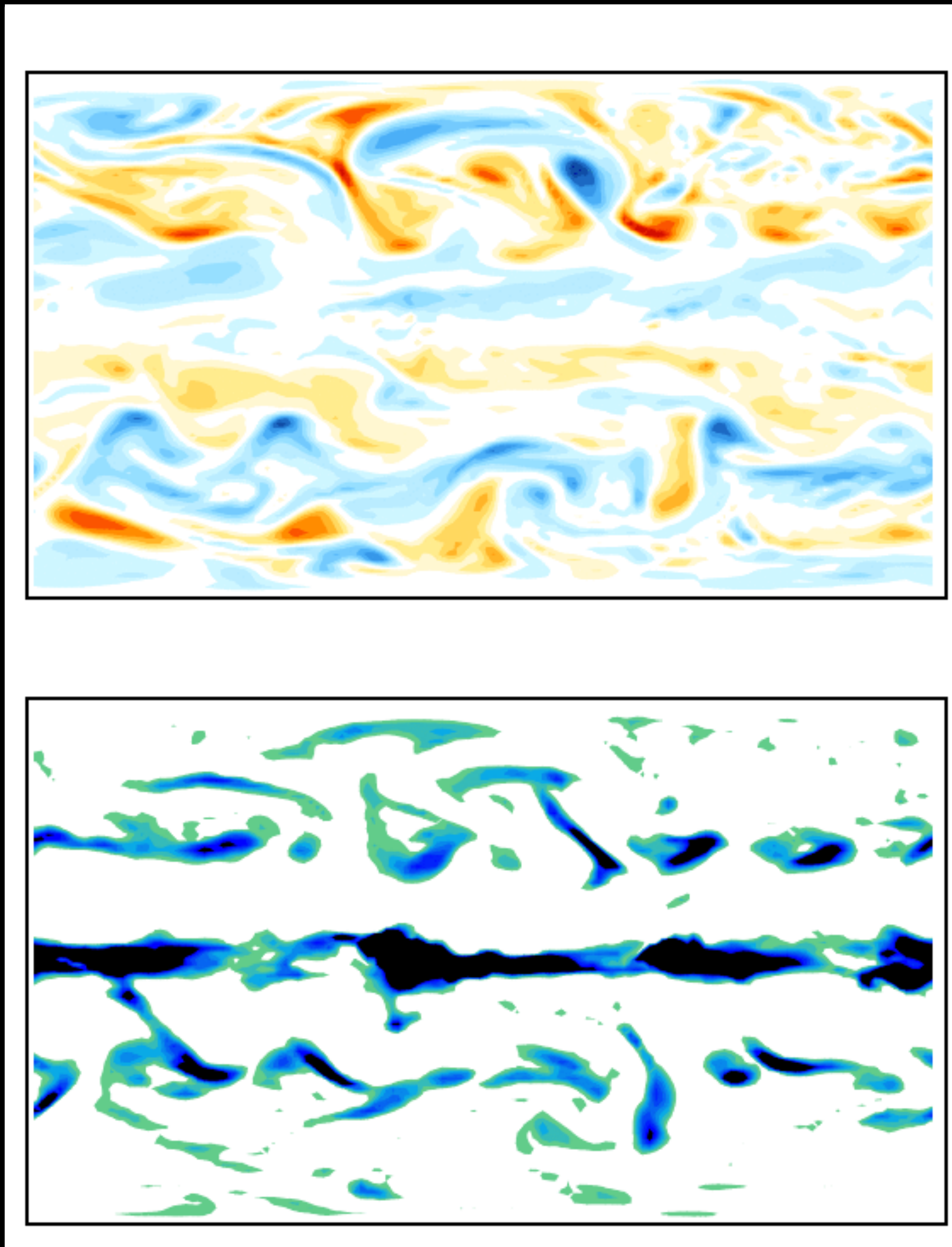
Easy to modify SST profile

Implemented by Brian Medeiros and Jim Benedict

http://www.cesm.ucar.edu/models/simpler-models/aquaplanet.html

500hPa vorticity

Total precipitation

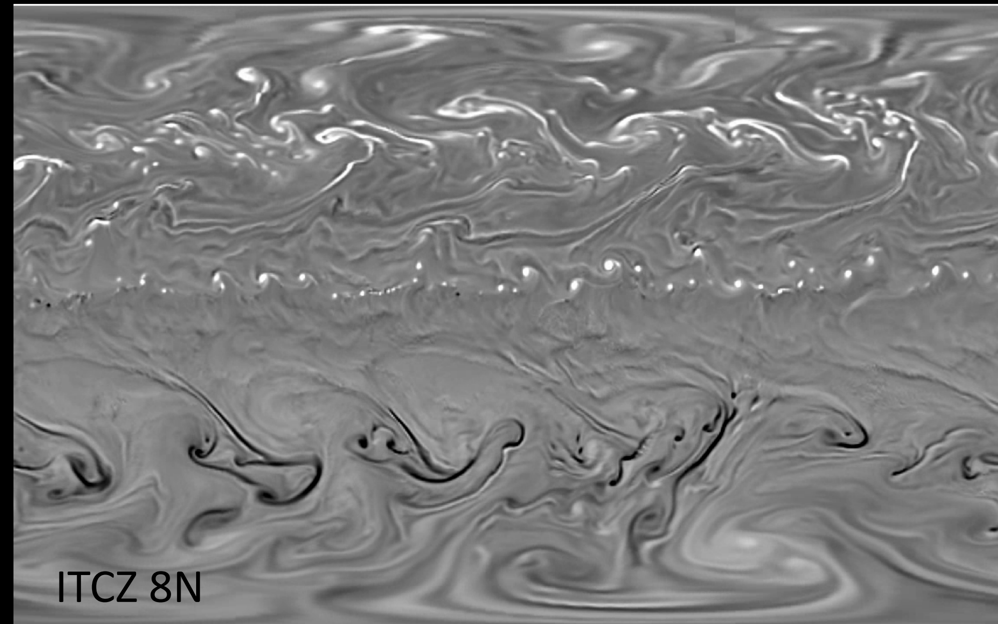


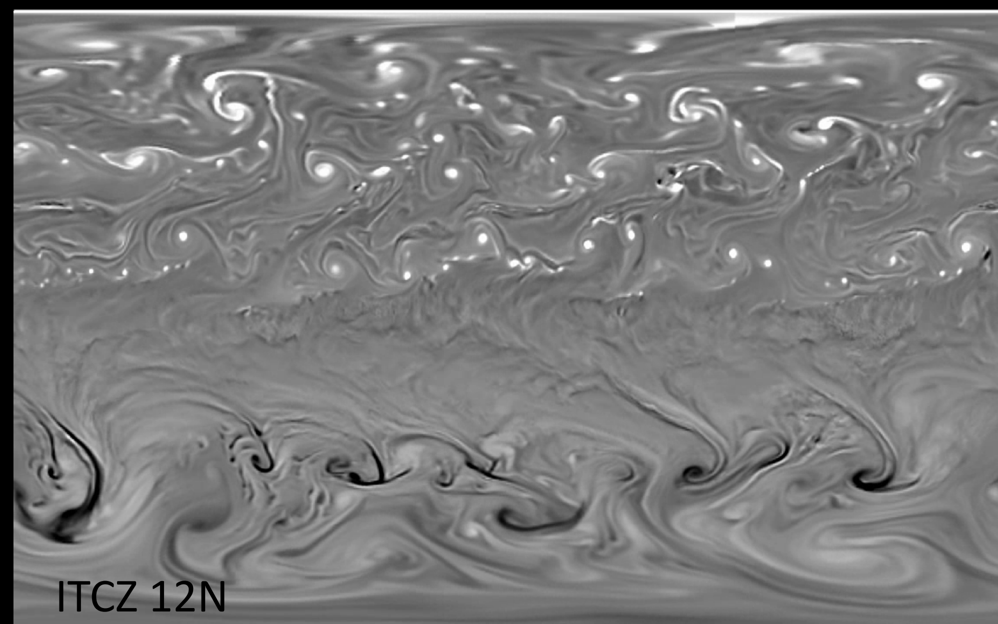
Example uses: sensitivity of hurricane formation to the latitude of the ITCZ

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

850hPa relative vorticity

White is positive (cyclonic)

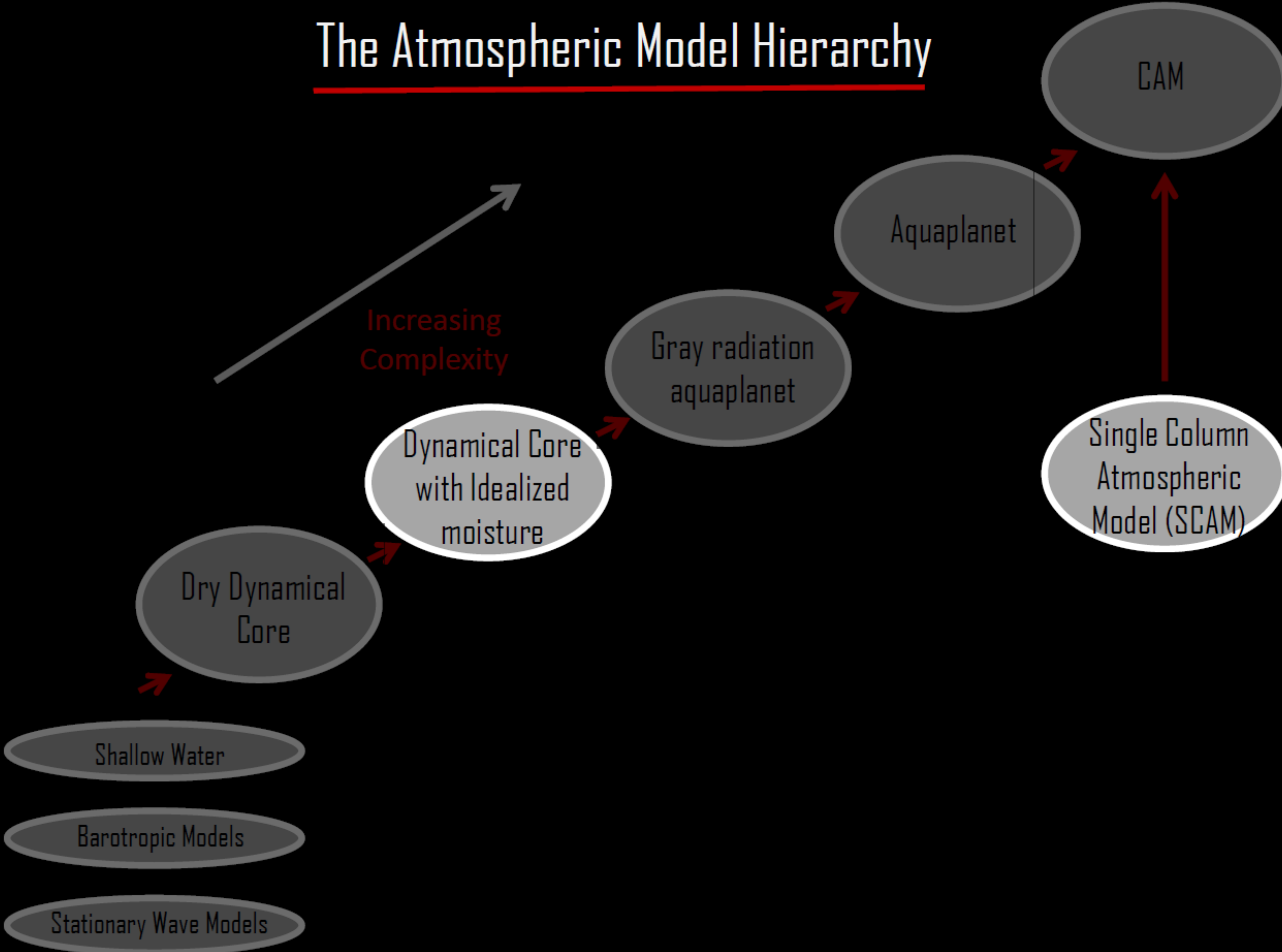




~40% increase in # of cyclones per degree poleward shift of the ITCZ from 8N

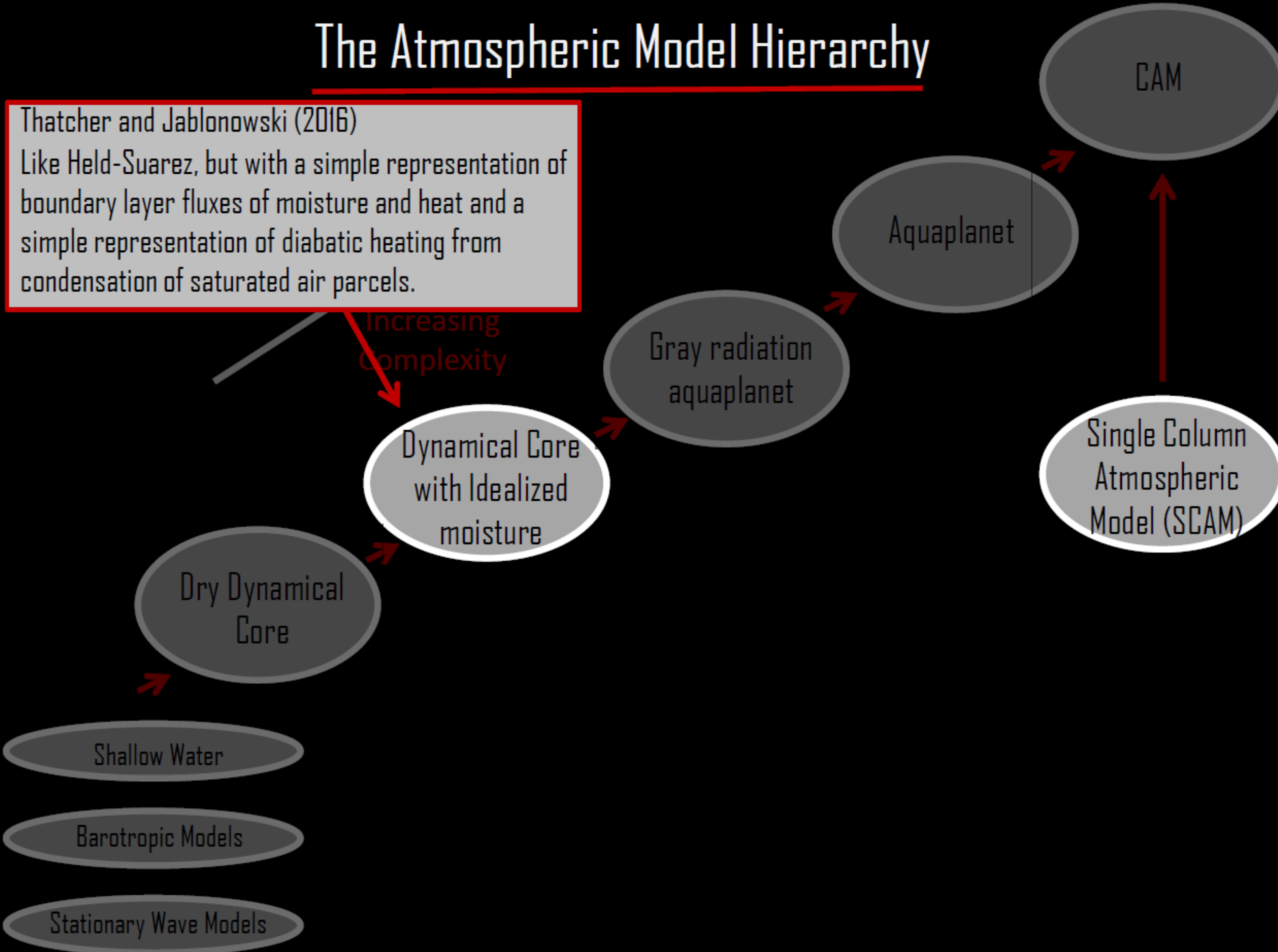
Movies courtesy of Tim Merlis (McGill University)

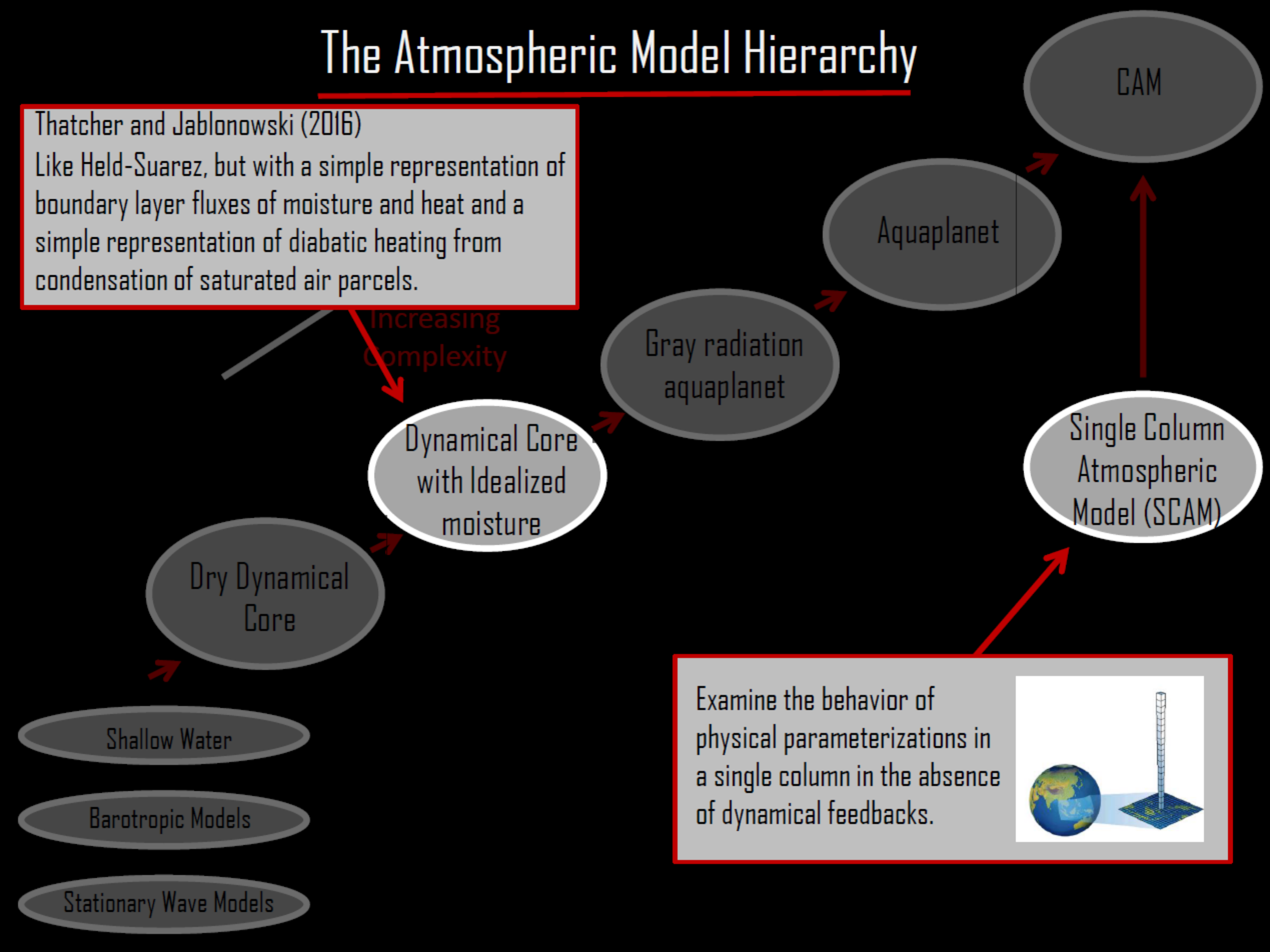
The Atmospheric Model Hierarchy



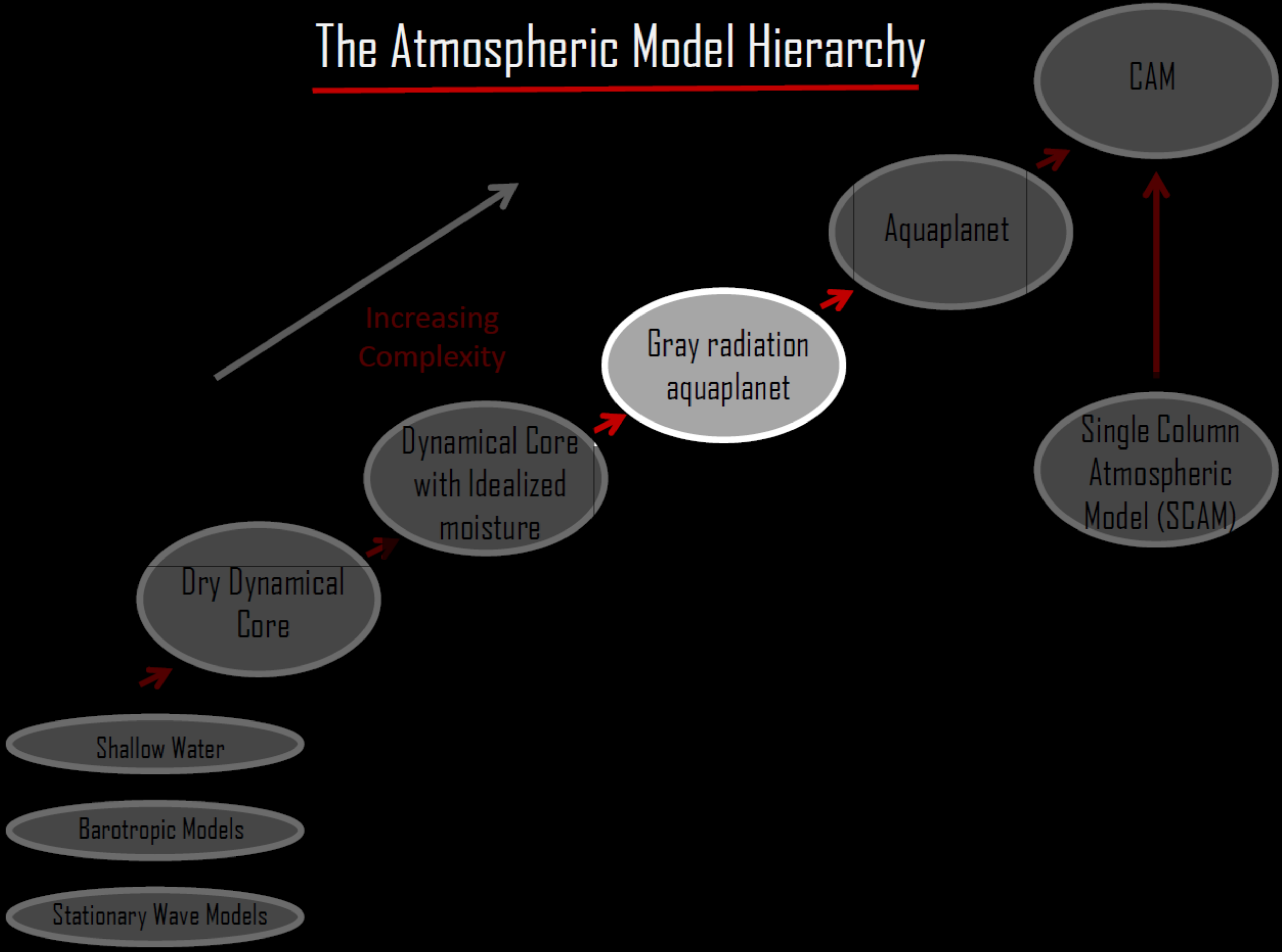
The Atmospheric Model Hierarchy

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.

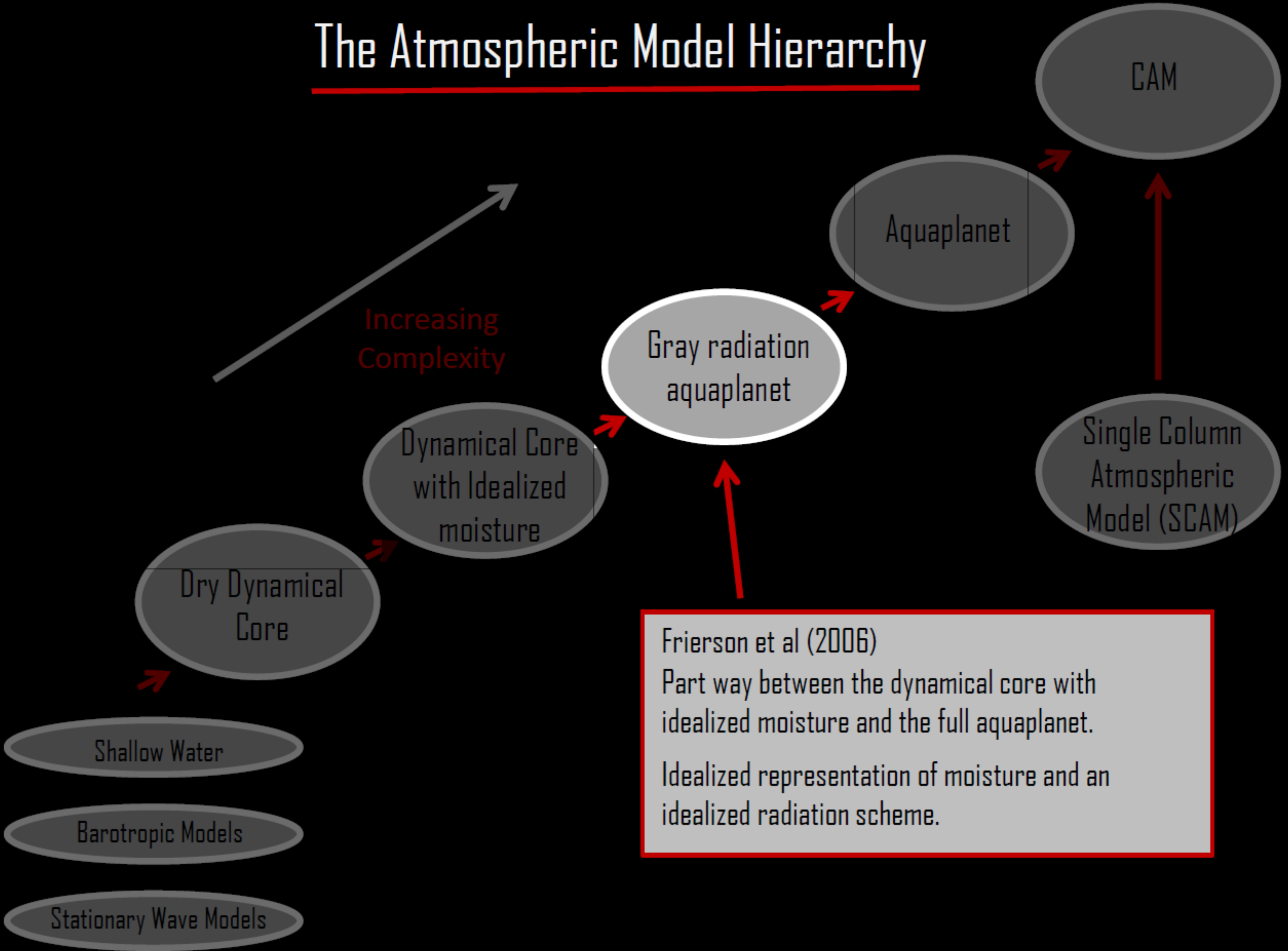



The Atmospheric Model Hierarchy
Thatcher and Jablonowski (2016)
Like Held-Suarez, but with a simple representation of boundary layer fluxes of moisture and heat and a simple representation of diabatic heating from condensation of saturated air parcels.
Increasing
Complexity
CAM
Aquaplanet
Gray radiation aquaplanet
Dynamical Core with Idealized moisture
Dry Dynamical Core
Single Column Atmospheric Model (SCAM)
Shallow Water
Barotropic Models
Stationary Wave Models
Examine the behavior of physical parameterizations in a single column in the absence of dynamical feedbacks.

The Atmospheric Model Hierarchy



The Atmospheric Model Hierarchy



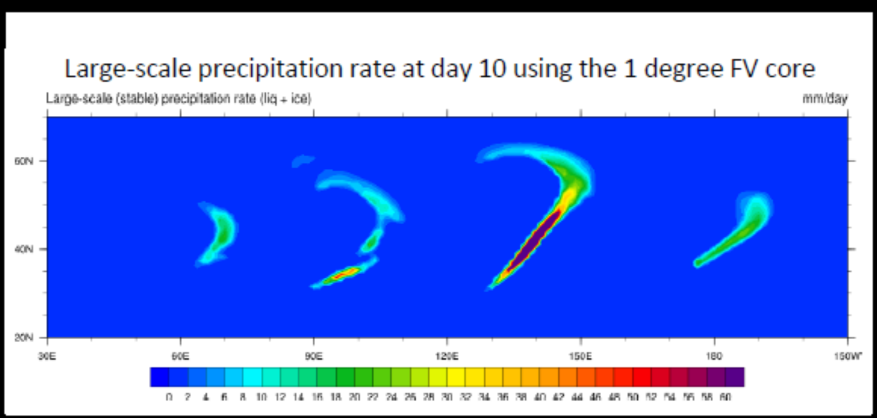
Dynamical Core Test Cases

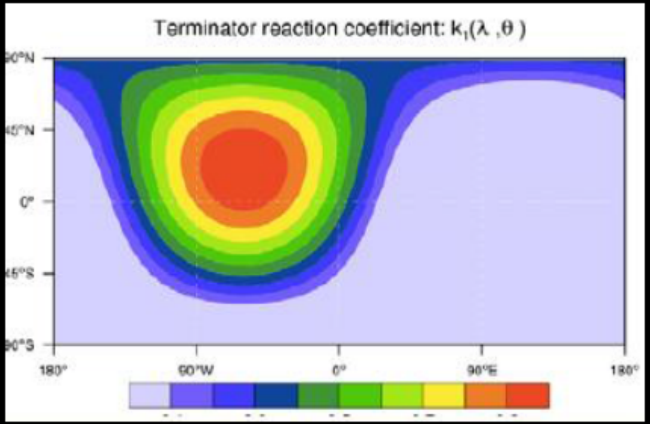
- Moist baroclinic wave with Kessler microphysics
  (Peter Lauritzen, Colin Zarzycki, Steve Goldhaber)

  Ulrich et al (2014) dry baroclinic wave with Kessler (1969) microphysics.

- Toy terminator chemistry (Lauritzen et al 2015)
  (Peter Lauritzen and Steve Goldhaber)

  Simple chemistry that mimics photolysis-driven processes near the solar terminator





http://www.cesm.ucar.edu/models/simpler-models/fkessler/index.html

Moist baroclinic wave with Kessler microphysics

Introduction

The simpler model configurations described in this page are in development and will be considered for integration into the standard CESM Simpler Models after consideration and discussion at upcoming Atmosphere Model Working Group meetings, and in consultation with Lorenzo Polvani (lmp@columbia.edu) or Amy Clement (aclement@rsmas.miami.edu).

Note, the following instructions are only valid for the development version of CESM. If you wish to run this test case configuration, please contact Peter Hjort Lauritzen (pel@ucar.edu) or Steve Goldhaber (goldy@ucar.edu)

The following describes a moist version of the dry baroclinic wave of Ullrich et al. (2014) with Kessler microphysics (Kessler, 1969) that was part of the Dynamical Core Model Intercomparison Project (DCMIP) 2016 test case suite.

Running the FKESSLER test case

After downloading the latest CESM code base, users may perform this test by following the procedures outlined below. See the CESM user's guide for more infomation on creating and running new cases.

Step 1: Create the FKESSLER test case

This can be done using the *create_newcase* script located in the directory $*CESM*/cime/scripts/ e.g., for the f09_f09 resolution

```
./create_newcase -compset FKESSLER -res f09_f09 -case $CASEDIR --run-unsupported
```

where the case directory is $*CASEDIR*. *-res f09_f09* sets the dynamical core to the finite-volume dynamical core at 1 degree horizontal resolution. Replace *-res f09_f09* with *-res f19_f19* for the 2 degree horizontal resolution finite-volume dynamical core or *-res ne30_ne30* for the 1 degree horizontal resolution spectral-element dynamical core. Any supported dynamical core and supported resolution for that particular dynamical core in CESM can be used (see source code file *components/cam/bld/config_files/horiz_grid.xml*).

Step 2: Configure the FKESSLER test case

The FKESSLER compset ensures that most of what is necessary to perform the test case is set up automatically. The default length of the simulation is set to 5 days, so in order to perform a 12 day test case, the following command must be invoked

```
./xmlchange STOP_OPTION=ndays,STOP_N=12
```

For short simulations generating relatively small output files it is sometimes convenient to turn off the automatic archiving functionality in the CESM scripts:

```
./xmlchange DOUT_S=FALSE
```

If you want to see what configuration options you are using use

```
./xmlquery CAM_CONFIG_OPTS
```

Step 3: Set up and build the FKESSLER test case

From within $CASEDIR run

```
./case.setup
```

```
./case.build
```

http://www.cesm.ucar.edu/models/simpler-models/terminator/index.html

'Toy' terminator chemistry

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This test extends the evaluation of transport schemes from prescribed advection of inert scalars to reactive species. The test consists of transporting two reacting chlorine-like species (Cl and Cl2). The sources and sinks for the two species are given by a simple, but non-linear, 'toy' chemistry. This chemistry mimics photolysis-driven processes near the solar terminator. As a result, strong gradients in the spatial distribution of the species develop near the edge of the terminator. Despite the large spatial variations in Cl and Cl2 the weighted sum Cly=Cl+2Cl2 should always be preserved regardless of the flow field. The terminator test demonstrates how well the advection/transport scheme preserves linear correlations. Physics-dynamics coupling can also be studied with this test. For more information on the terminator chemistry see Lauritzen et al. (2015).

The terminator chemistry can be turned on in any CAM configuration. The terminator chemistry flag will add the two tracers, Cl and Cl2, and invoke the idealized chemical reactions. For simplicity we document the terminator chemistry with the moist baroclinic wave with Kessler microphysics below.

Running the FKESSLER test case (with terminator chemistry)

After downloading the latest CESM code base, users may perform this test by following the procedures outlined below. See the CESM user's guide for more infomation on creating and running new cases.

The FKESSLER compset automatically turns on the terminator chemistry.

Step 1: Create the FKESSLER test case

This can be done using the *create_newcase* script located in the directory $*CESM*/cime/scripts/ e.g., for the f09_f09 resolution

```
./create_newcase -compset FKESSLER -res f09_f09 -case $CASEDIR --run-unsupported
```

where the case directory is $*CASEDIR*. *-res f09_f09* sets the dynamical core to the finite-volume dynamical core at 1 degree horizontal resolution. Replace *-res f09_f09* with *-res f19_f19* for the 2 degree horizontal resolution finite-volume dynamical core or *-res ne30_ne30* for the 1 degree horizontal resolution spectral-element dynamical core. Any supported dynamical core and supported resolution for that particular dynamical core in CESM can be used (see source code file *components/cam/bld/config_files/horiz_grid.xml*).

Step 2: Configure the FKESSLER test case

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```

We’d like to hear from you

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- If you make use of idealized configurations of CESM, please contribute your paper to the CESM simpler models publications page and mention it in your acknowledgements. This will ensure continued support.

www.cesm.ucar.edu/models/simpler-models/simplerpubs.html

Publications using CESM simpler models

If you would like your publication to be included on this page, please send it to Isla Simpson (islas@ucar.edu)

Publications in alphabetical order:

- Benedict, J. J., B. Medeiros, A. C. Clement, A. G. Pendergrass (2017): Sensitivities of the hydrologic cycle to model physics, grid resolution, and ocean type in the aquaplanet Community Atmosphere Model, JAMES, 9, 1307-1324, doi:10.1002/2016MS000891
- Medeiros, B. D., D. L. Williamson, J. G. Olson (2016): Reference aquaplanet climate in the Community Atmosphere Model, Version 5, JAMES, 8, 406-424, doi:10.1003/2015MS000593

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Acknowledgement of CESM simpler models and publications

In order to ensure continued support for simpler models efforts within CESM, we would like to be aware of research that has been performed using these configurations. Please consider adding the following acknowledgement to your publications using CESM simpler models.

The "insert_your_model" used in this study was made available through the Simpler Models Initiative as part of the Community Earth System Model project; this initiative is supposed by the National Center for Atmospheric Research under the sponsorship of the National Science Foundation.

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- If you have an idealized configuration that you've developed / would like to develop and you would like to make this available to the wider community, get in touch

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

For dry dynamical core: Isla Simpson, islas@ucar.edu

For aquaplanet: Brian Medeiros, brianpm@ucar.edu

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