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)

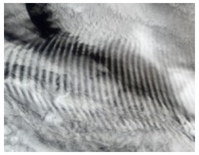
Dynamics

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

Convection Schemes

Moist Processes

Cloud Physics



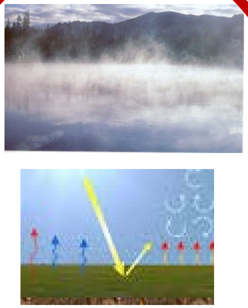
Gravity Wave Drag

Physical Parameterizations

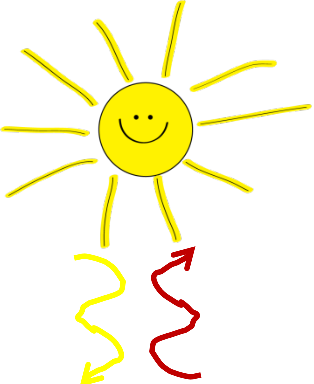
Land (CLM)

Prescribed SSTs

Prescribed ICE



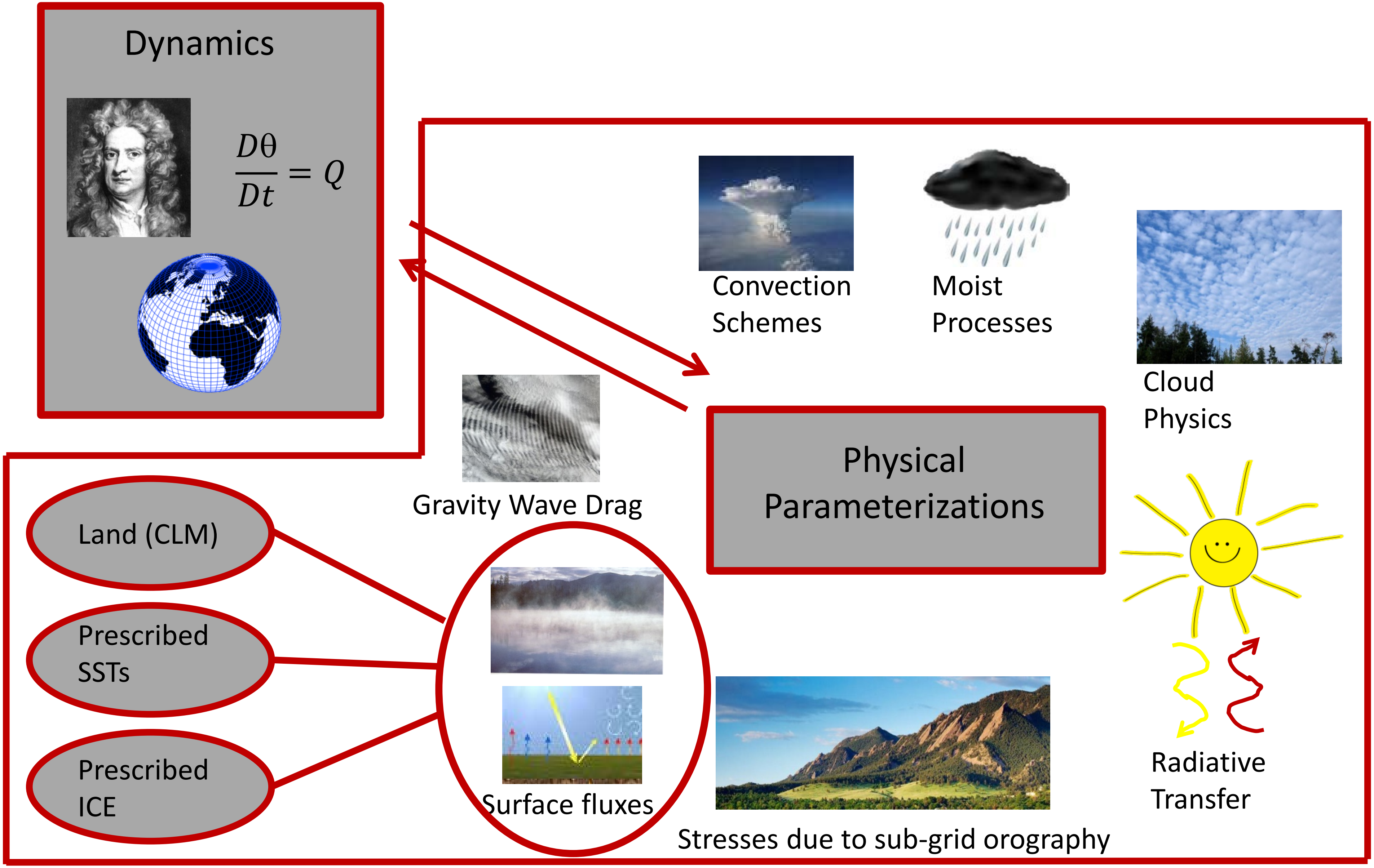
Surface fluxes



Radiative Transfer

Stresses due to sub-grid orography

The Community Atmosphere Model (CAM)



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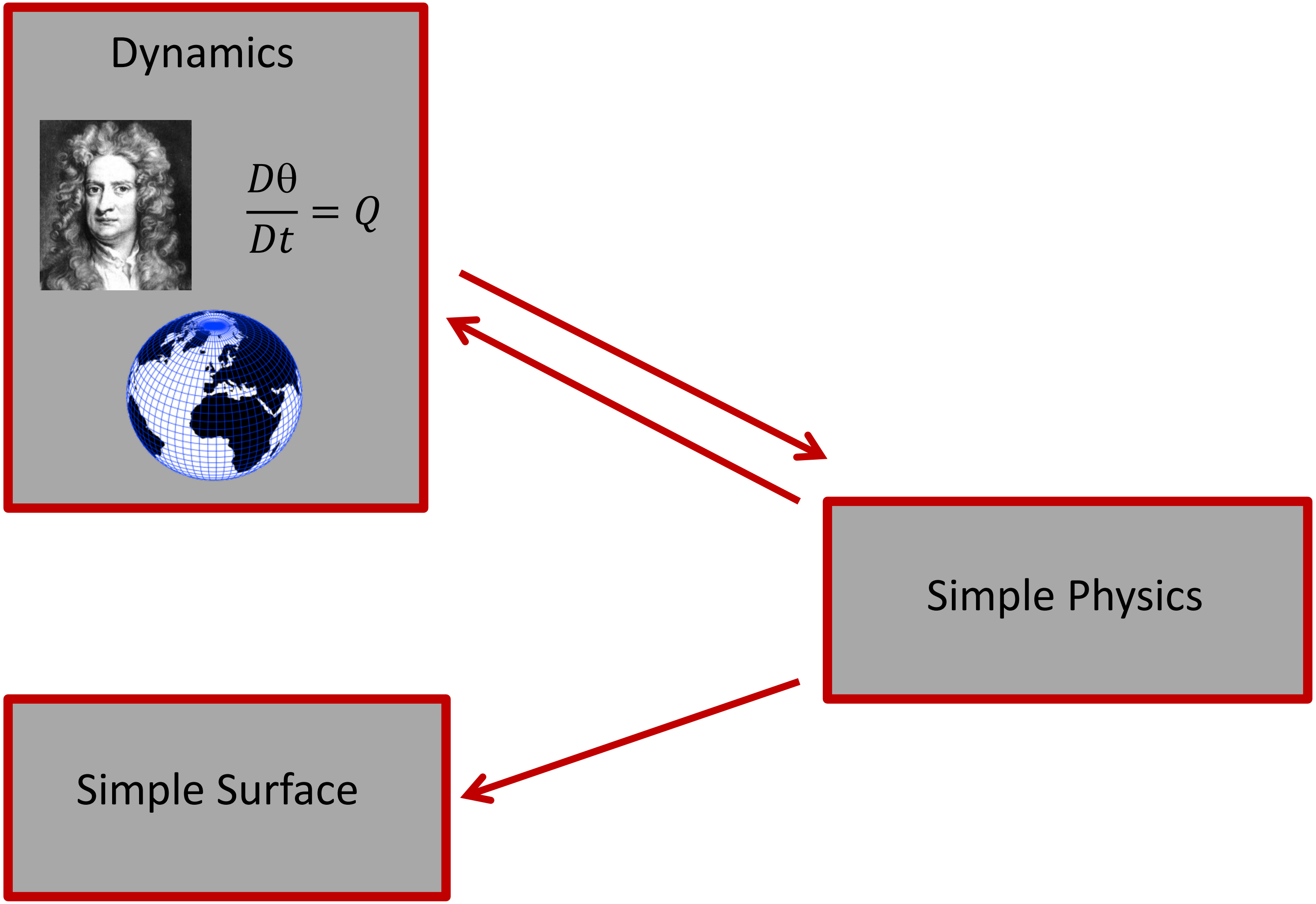


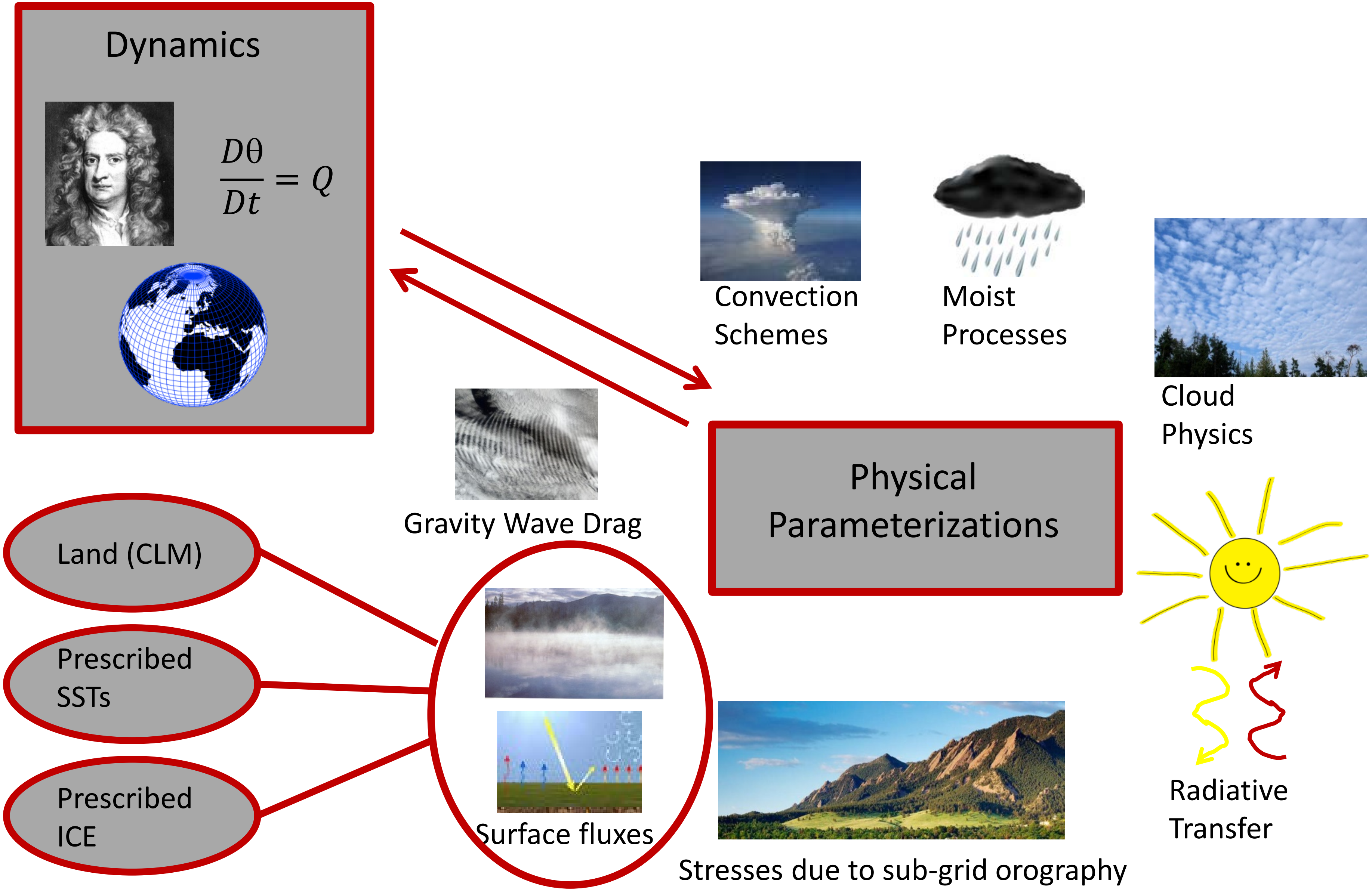
Dynamics

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

Simple Physics

Simple Surface

The Community Atmosphere Model (CAM)



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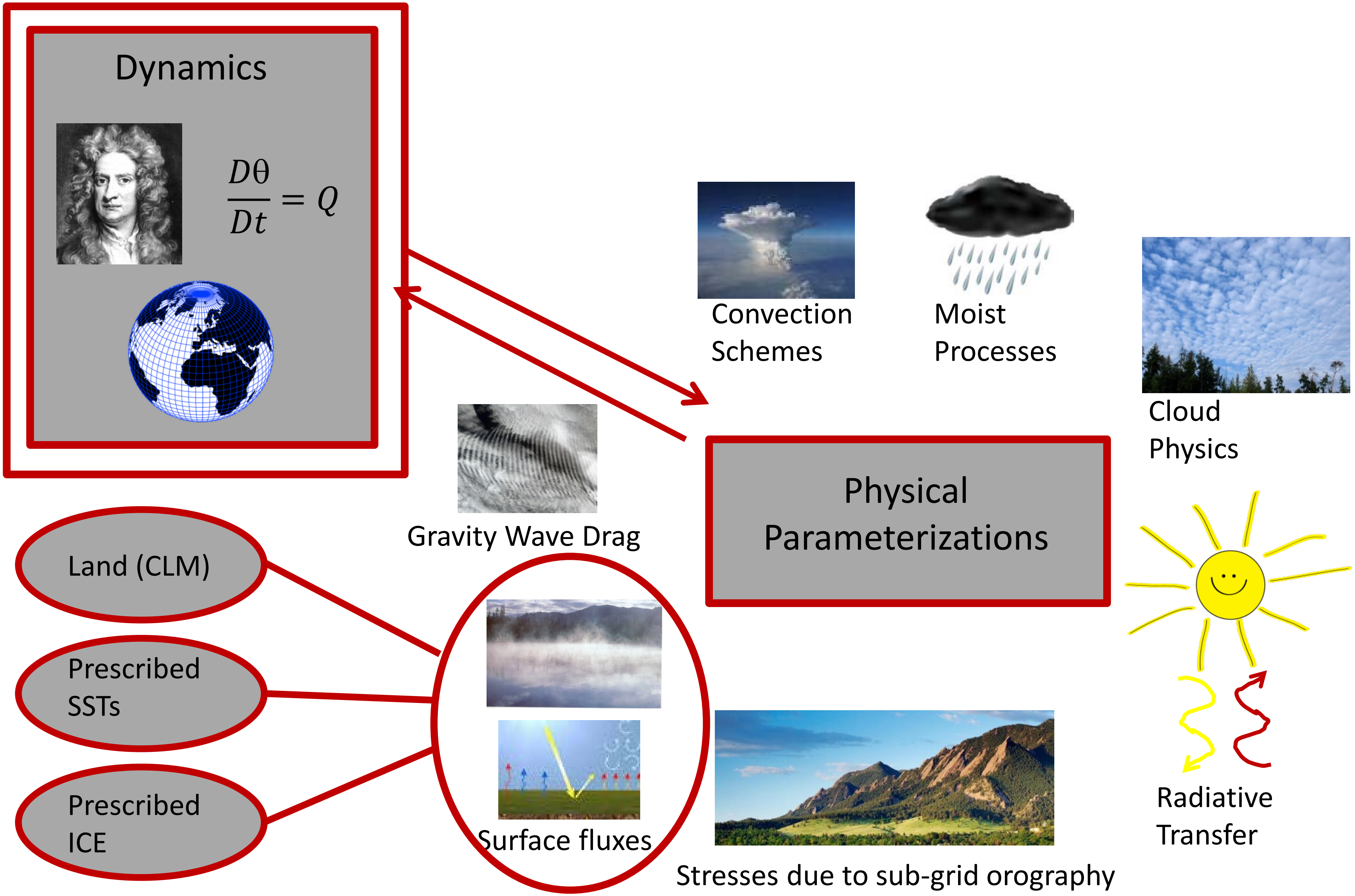

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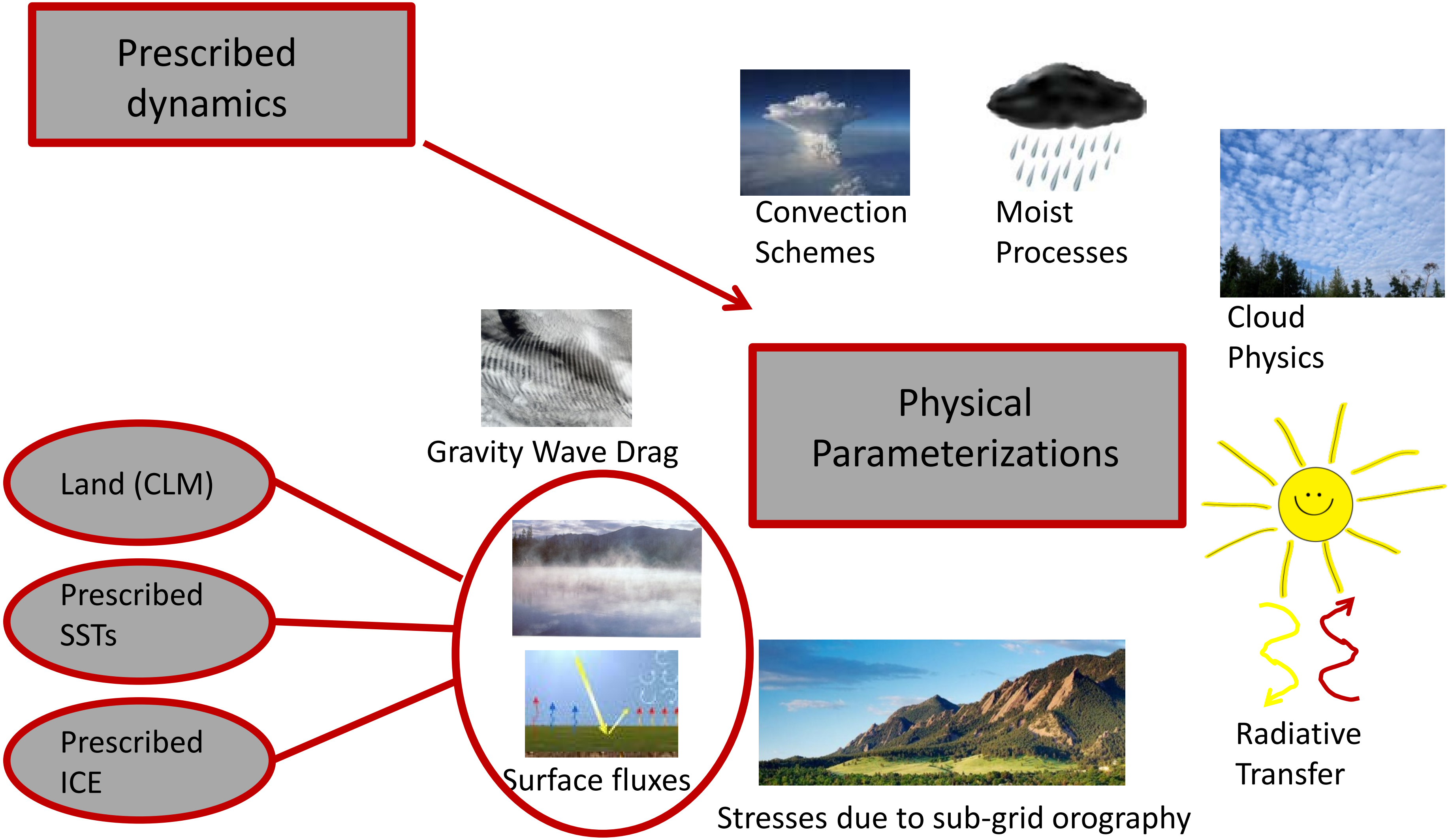

Prescribed dynamics

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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 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.

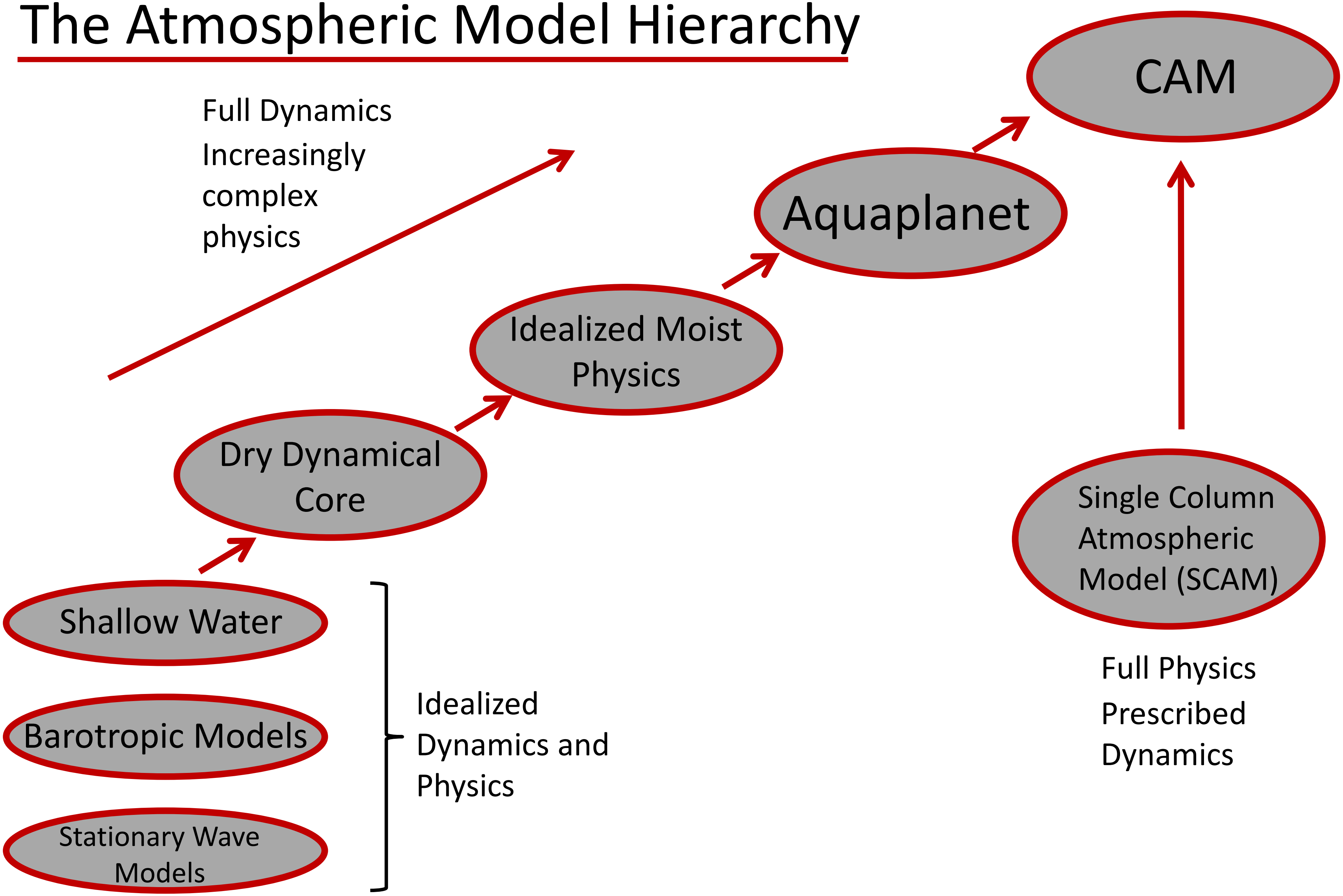
Useful Teaching Tool

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 and documenting them.

Others required more work…

The Atmospheric Model Hierarchy



Full Dynamics

Increasingly complex physics

CAM

Aquaplanet

Idealized Moist Physics

Dry Dynamical Core

Shallow Water

Barotropic Models

Stationary Wave Models

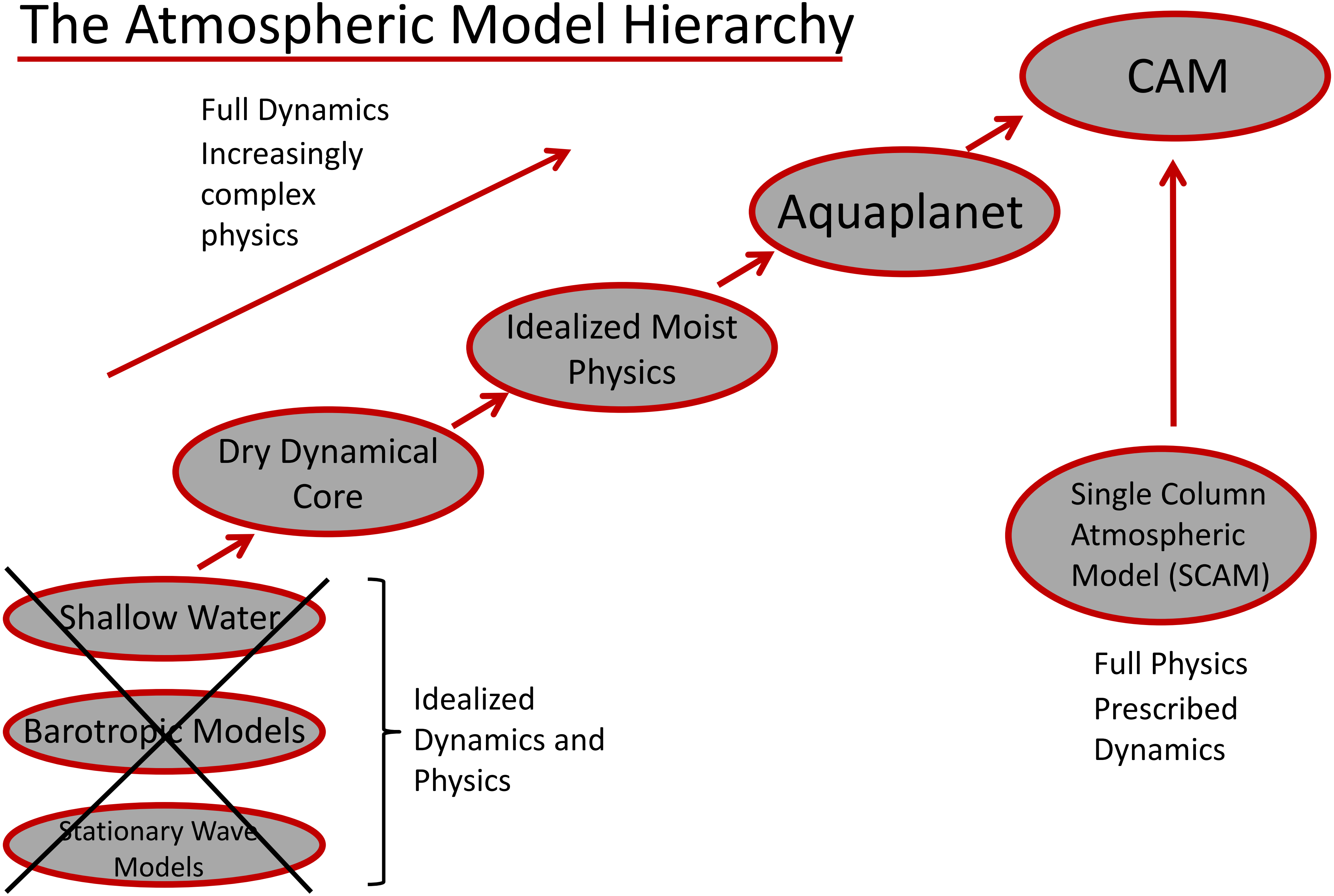
Idealized Dynamics and Physics

Single Column Atmospheric Model (SCAM)

Full Physics

Prescribed Dynamics

The Atmospheric Model Hierarchy



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~~Shallow Water~~

~~Barotropic Models~~

~~Stationary Wave Models~~

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Full Physics
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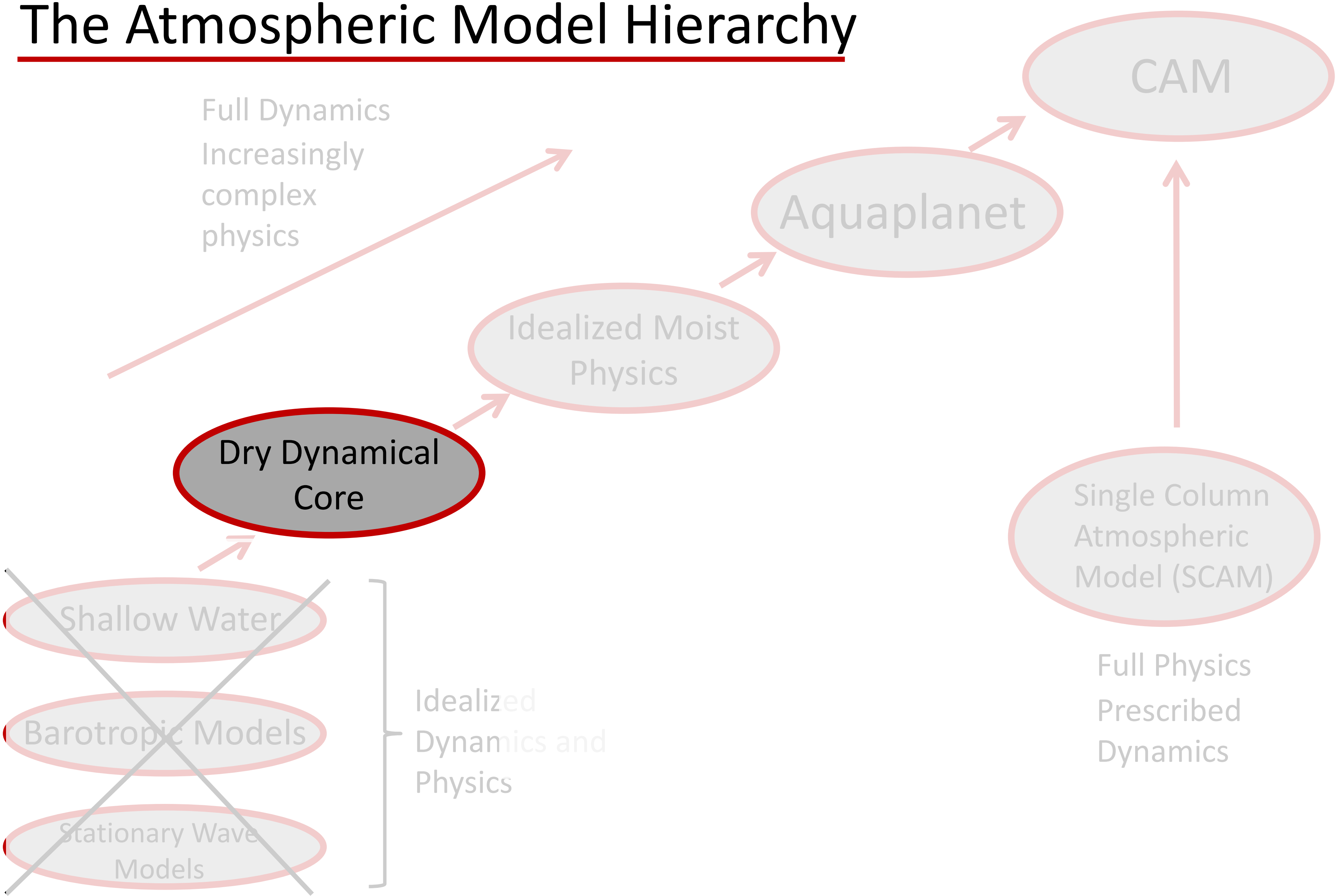

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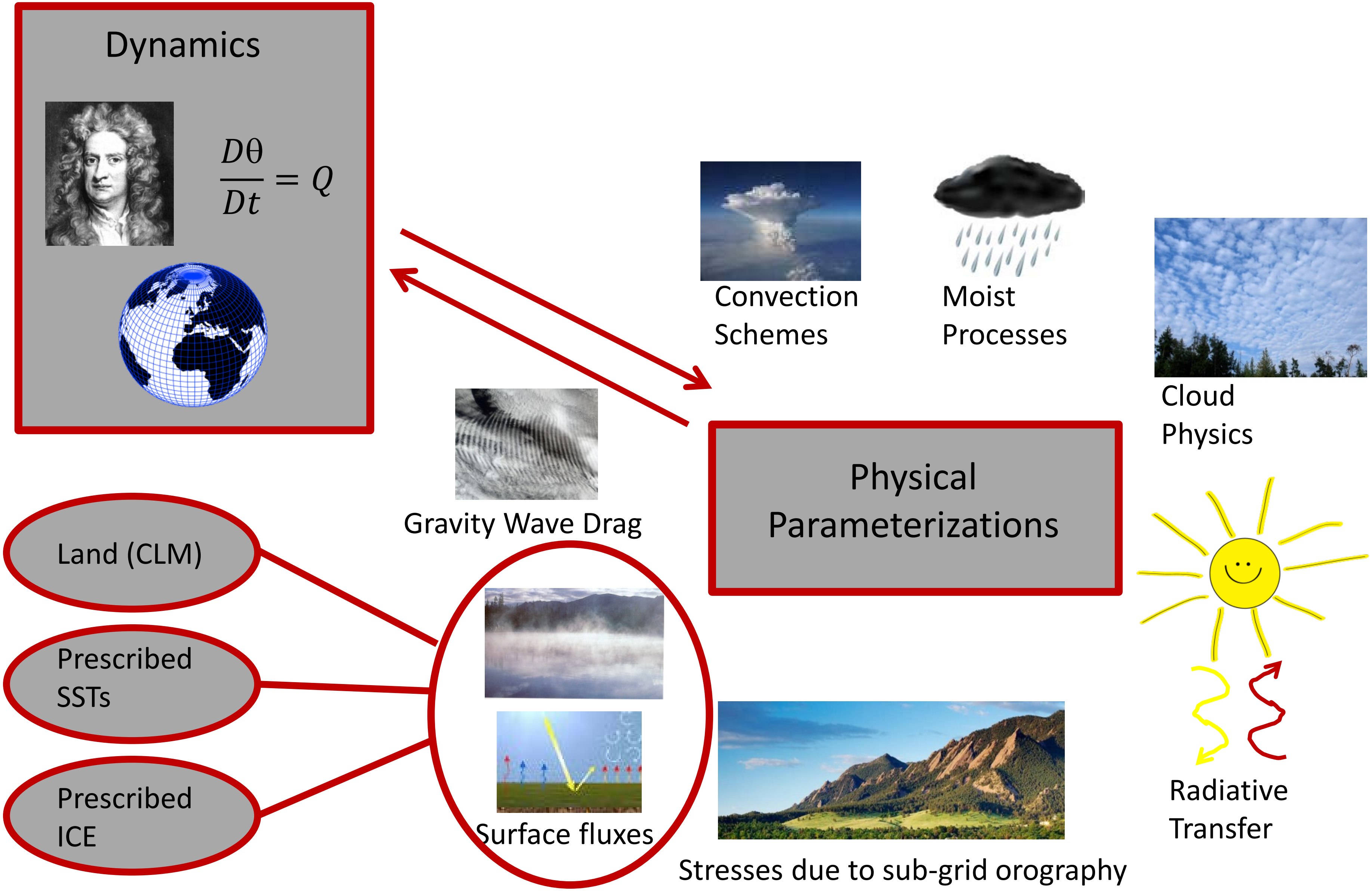

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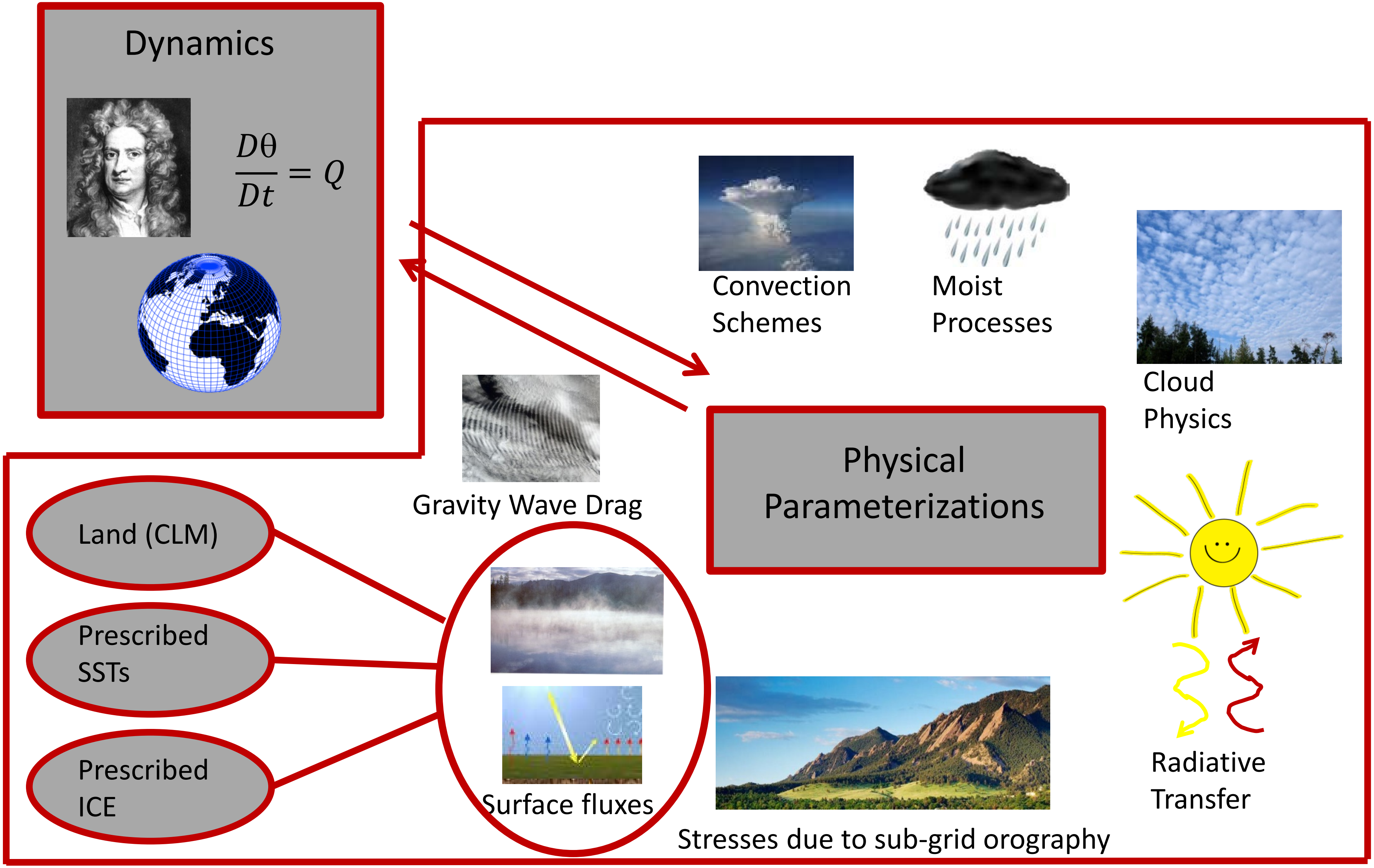

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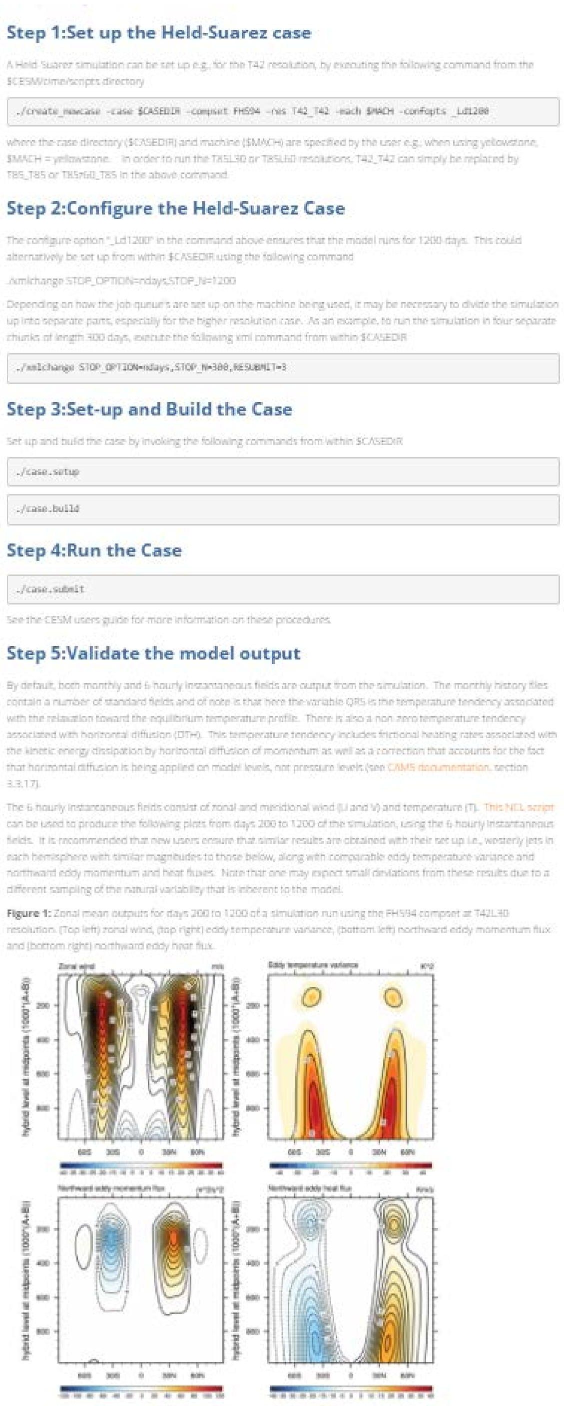
$$\frac{\partial \vec{v}}{\partial t} = \cdots - k_v \vec{v}$$

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



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.

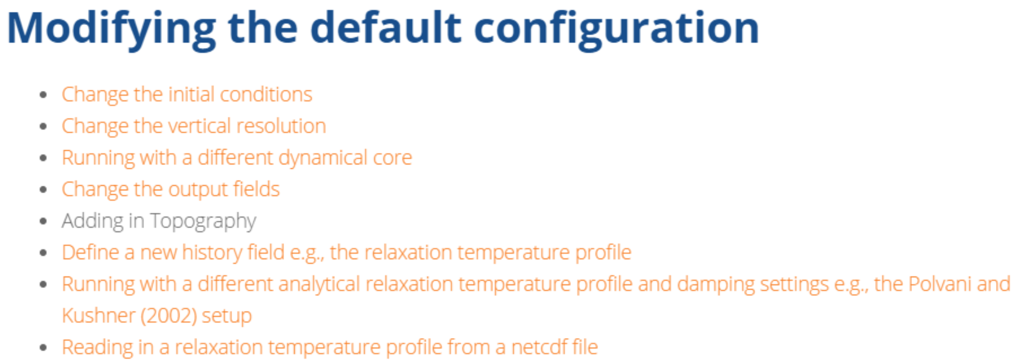
Figure 1: Zonal mean outputs for days 200 to 1200 of a simulation run using the FHS94 compset at T42L30 resolution. (Top left) zonal wind, (top right) eddy temperature variance, (bottom left) northward eddy momentum flux and (bottom right) northward eddy heat flux.

Step-by-step instructions

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

Instructions on:

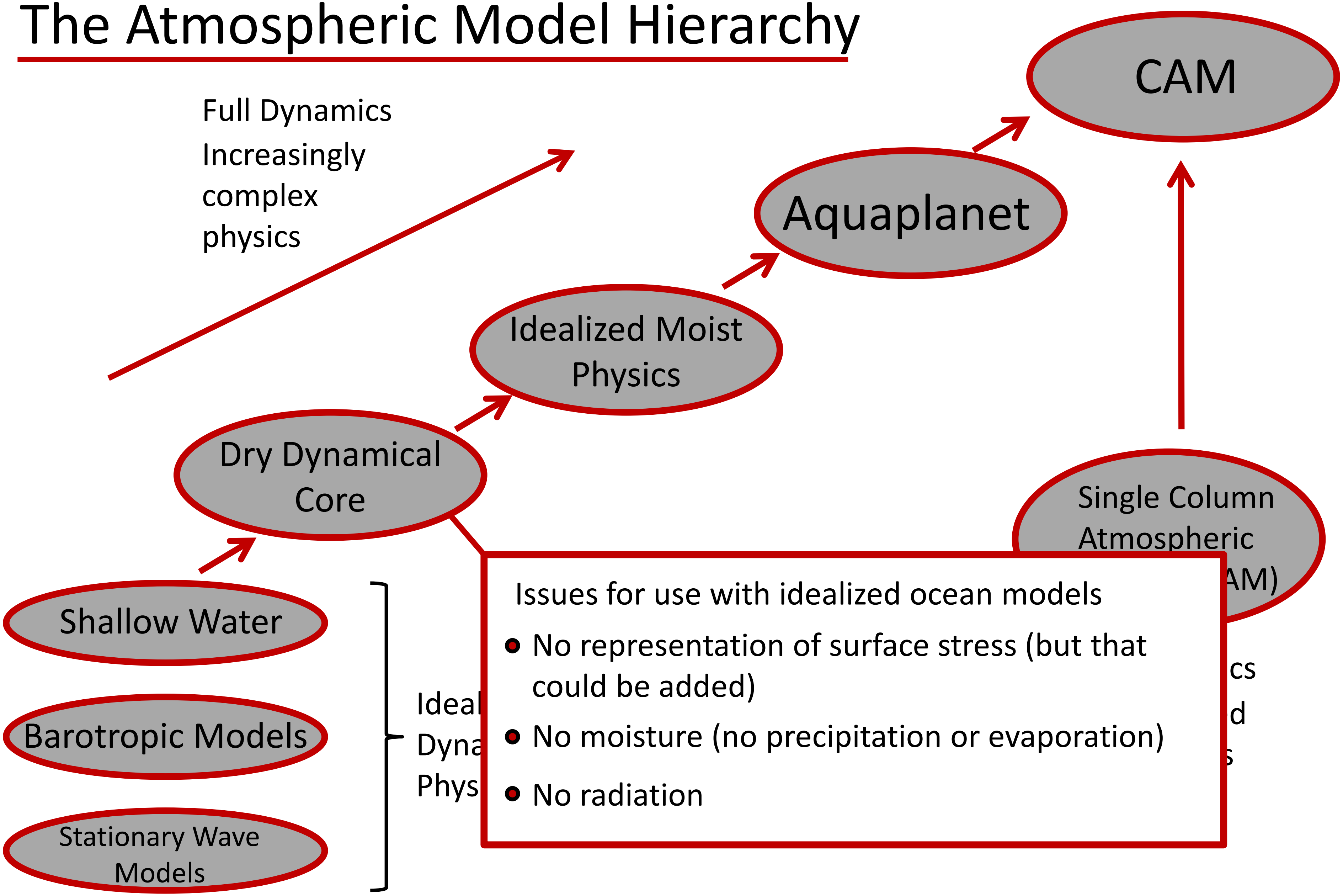
- Running with a different dynamical core
- Changing the vertical and horizontal resolution
- Running with topography
- Running with a different analytical relaxation temperature profile (Polvani and Kushner 2002 stratosphere as an example)
- Running with a relaxation temperature profile from netcdf



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

Single Column
Atmospheric
AM)

Shallow Water

Barotropic Models

Stationary Wave Models

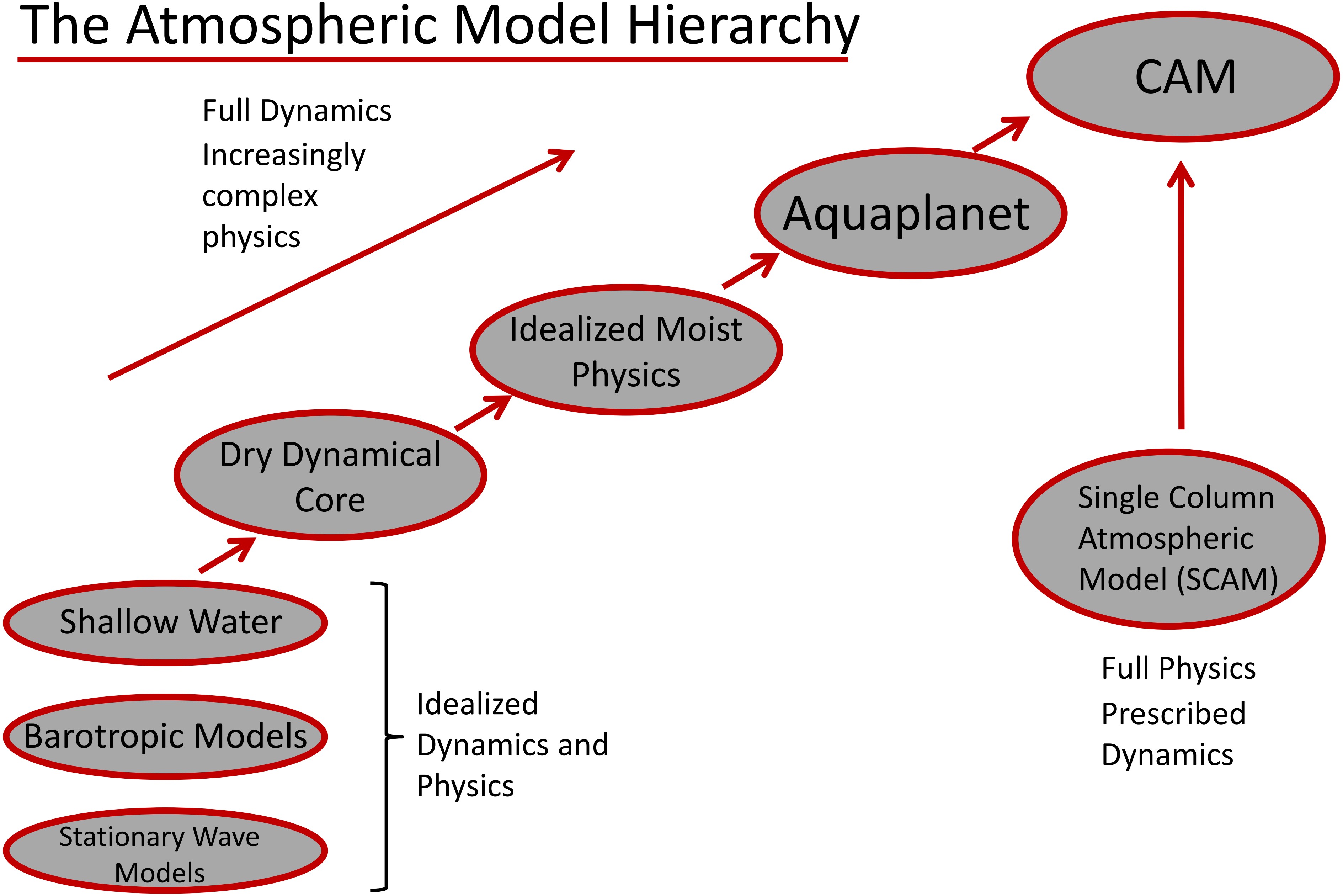
Ideal
Dyna
Phys

cs
d
s

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

The Atmospheric Model Hierarchy



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Dynamics and
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Single Column Atmospheric Model (SCAM)

Full Physics
Prescribed
Dynamics

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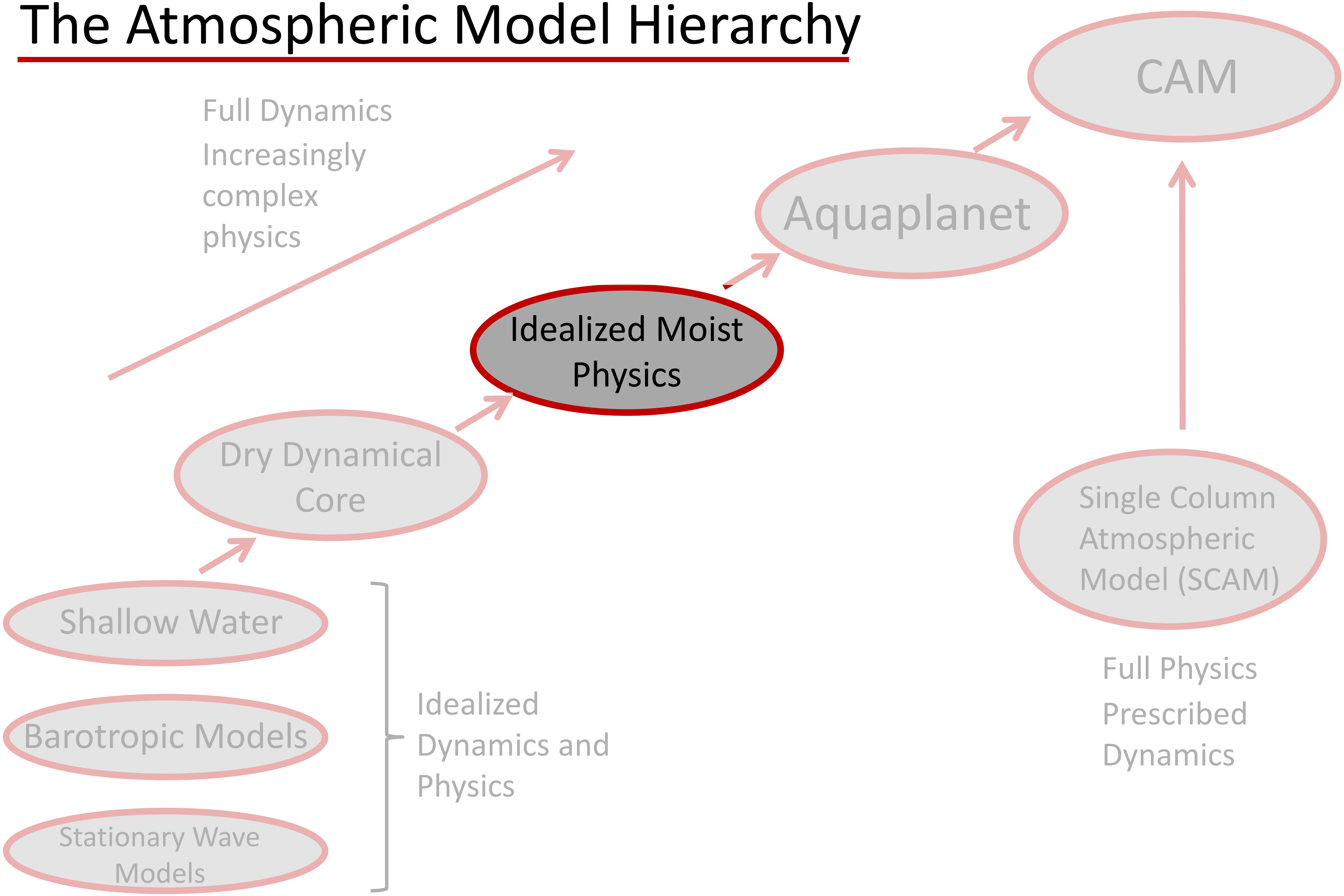

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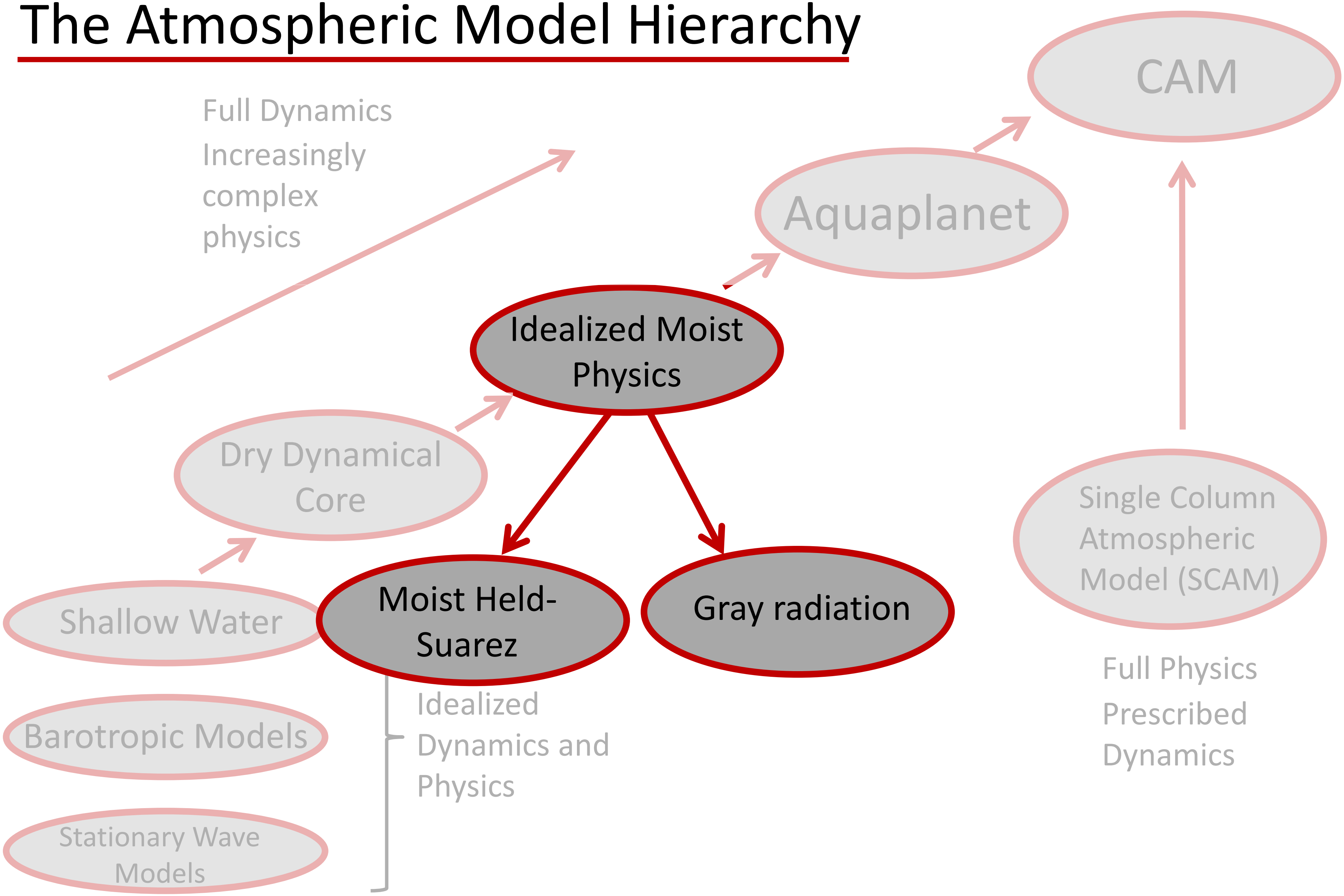

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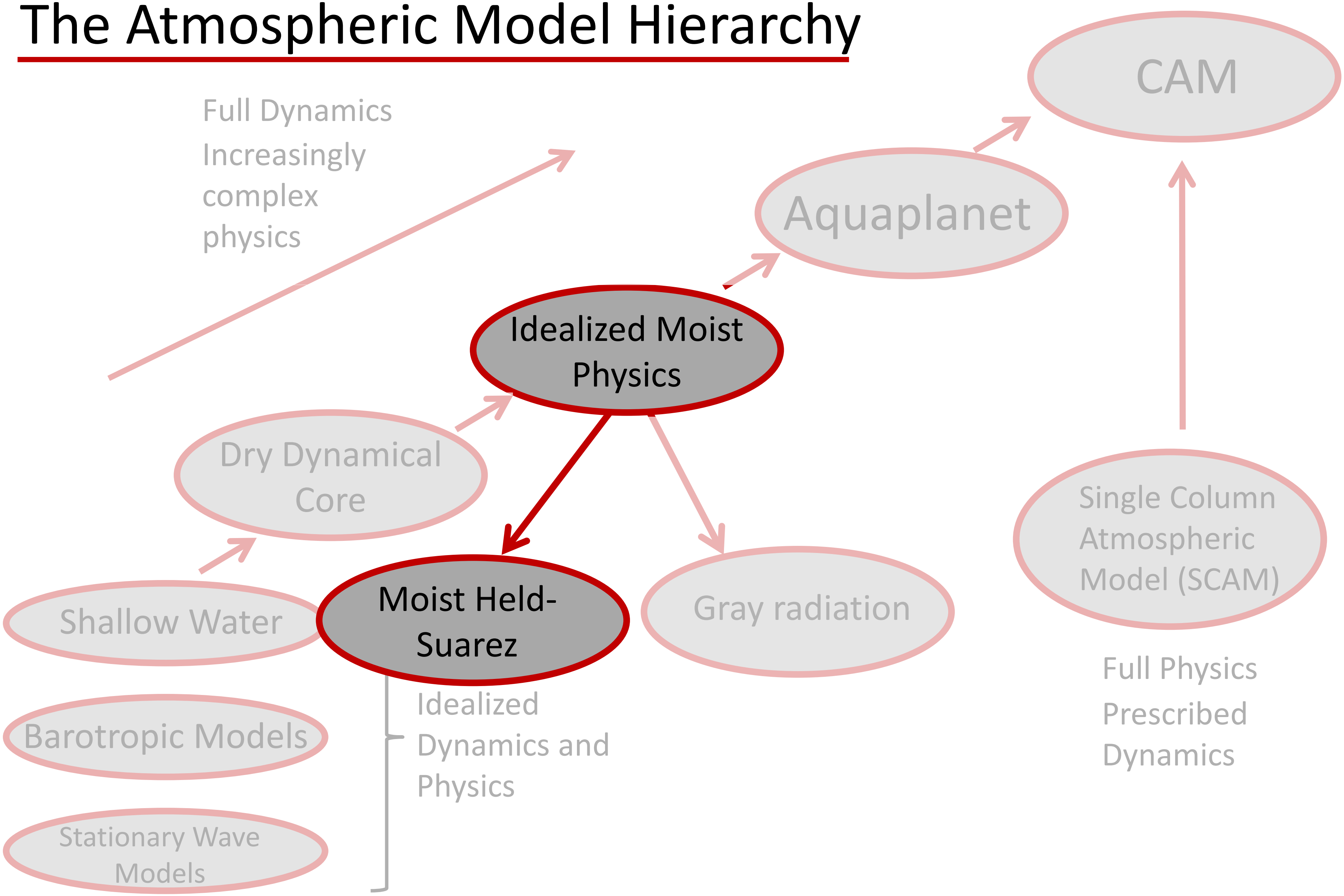

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The Community Atmosphere Model (CAM)

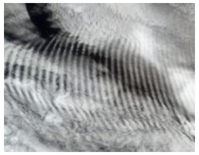
Dynamics

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

Convection
Schemes

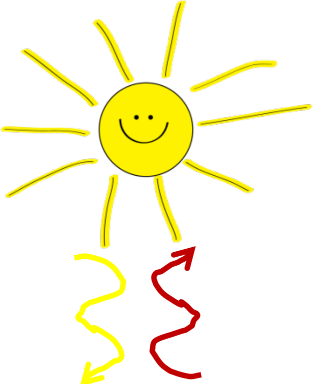
Moist
Processes

Cloud
Physics



Gravity Wave Drag

Physical
Parameterizations

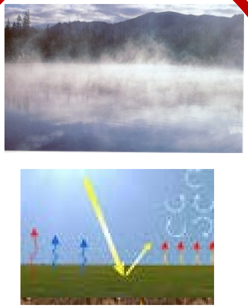


Radiative
Transfer

Land (CLM)

Prescribed
SSTs

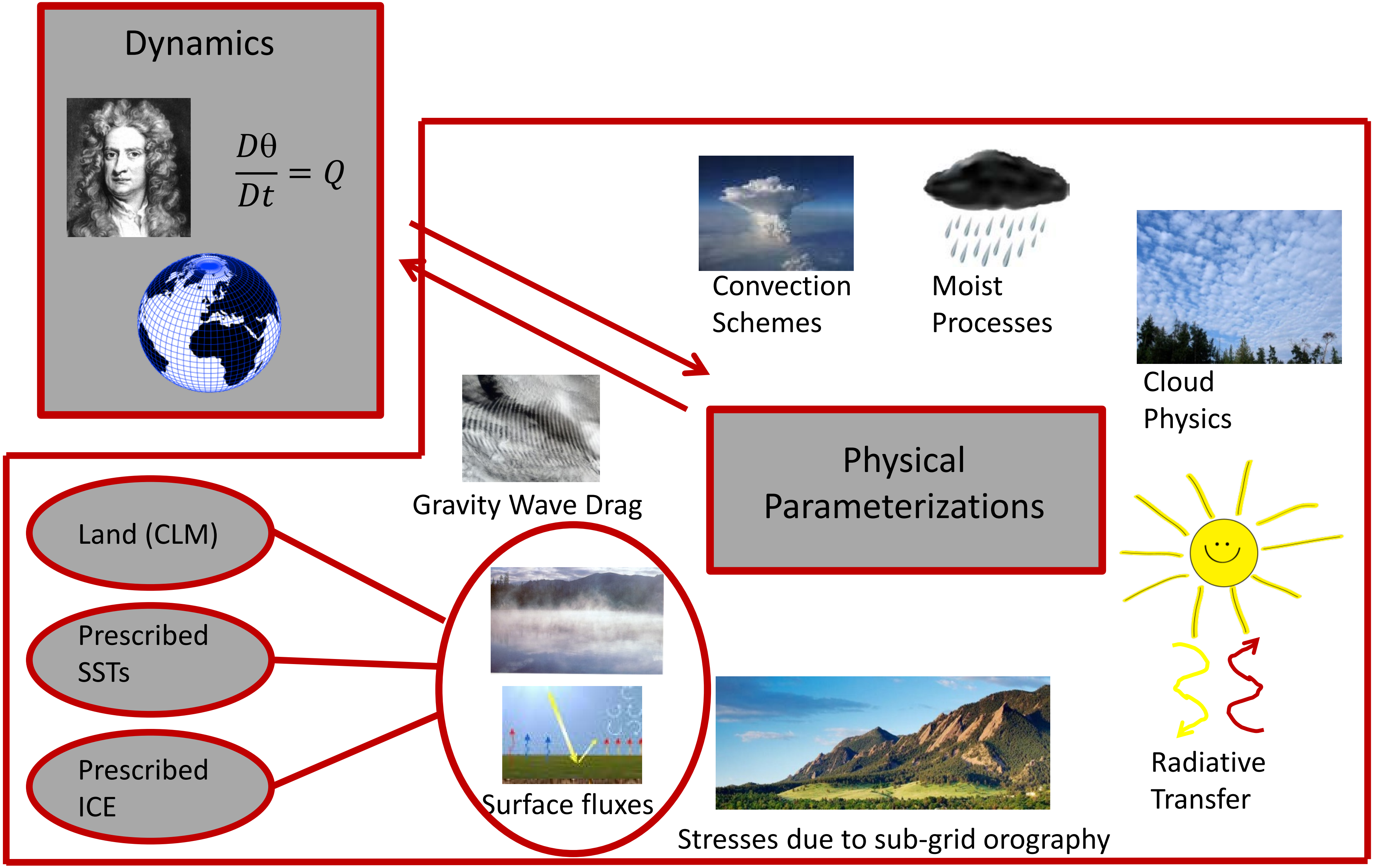
Prescribed
ICE



Surface fluxes

Stresses due to sub-grid orography

The Community Atmosphere Model (CAM)



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

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)

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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.

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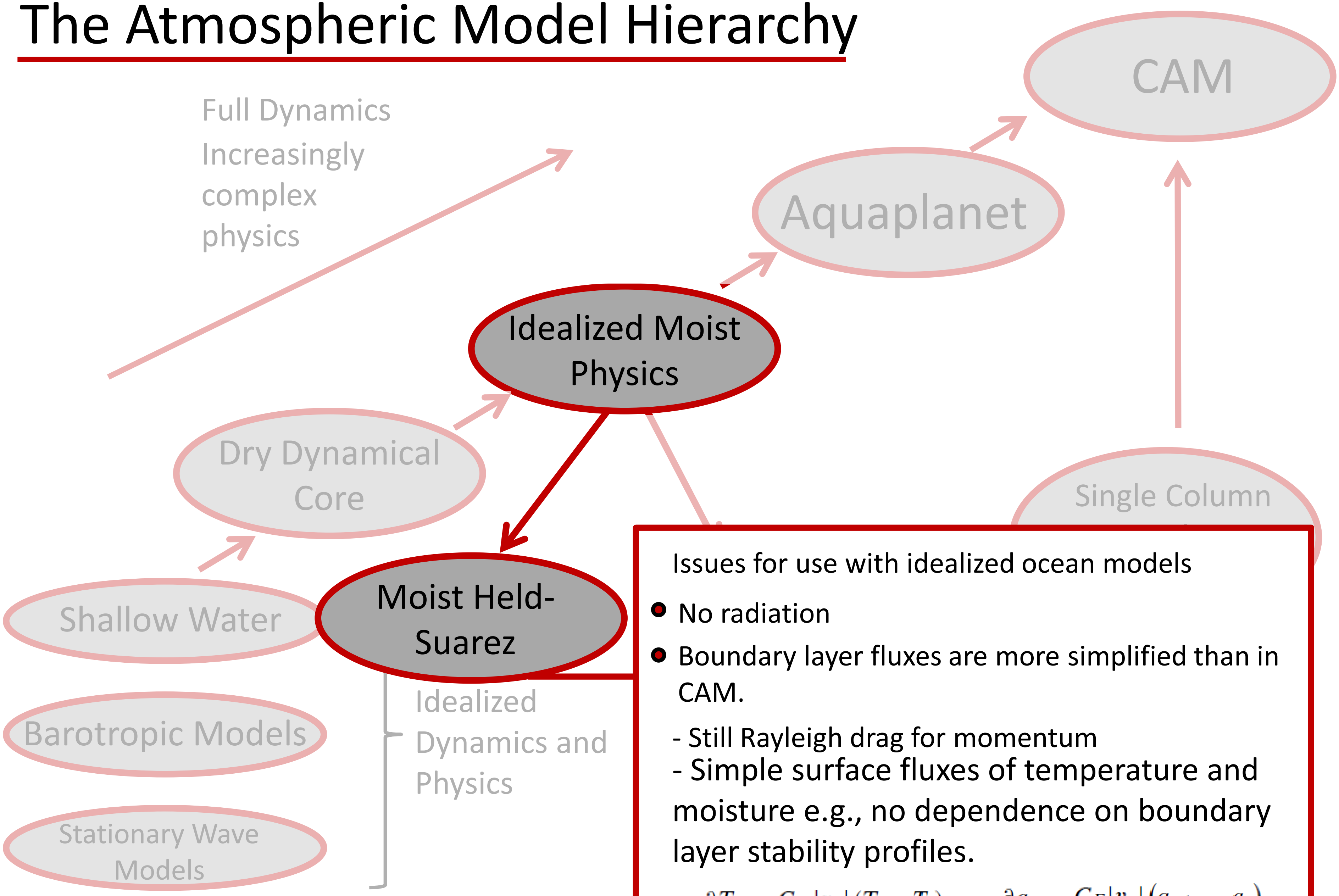

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Increasingly complex physics

CAM

Aquaplanet

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Single Column

Shallow Water

Moist Held-Suarez

Barotropic Models

Stationary Wave Models

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.

$$\frac{\partial T_a}{\partial t} = \frac{C_H |\mathbf{v}_a| (T_s - T_a)}{z_a} \qquad \frac{\partial q_a}{\partial t} = \frac{C_E |\mathbf{v}_a| \left(q_{sat,s} - q_a\right)}{z_a}$$

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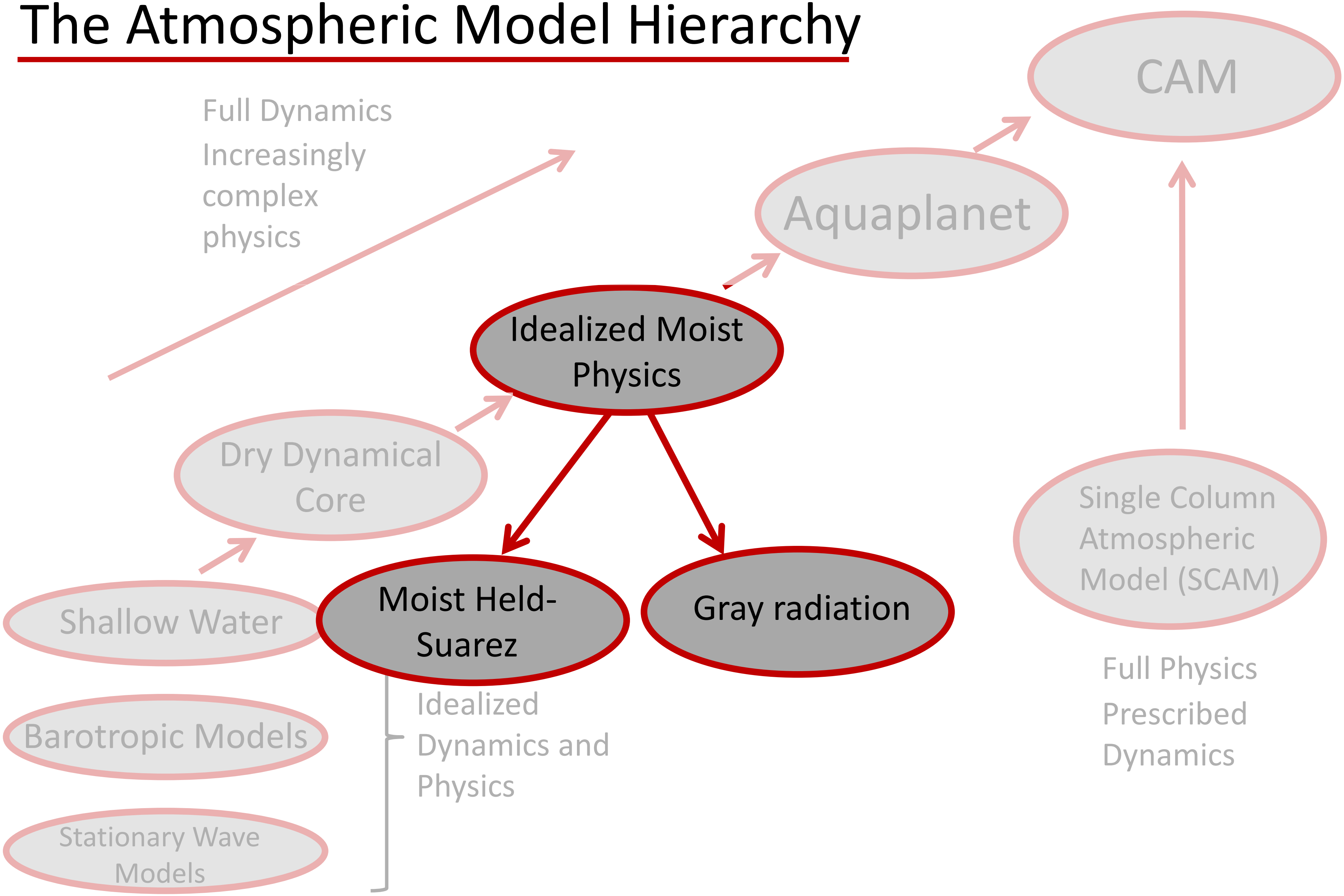

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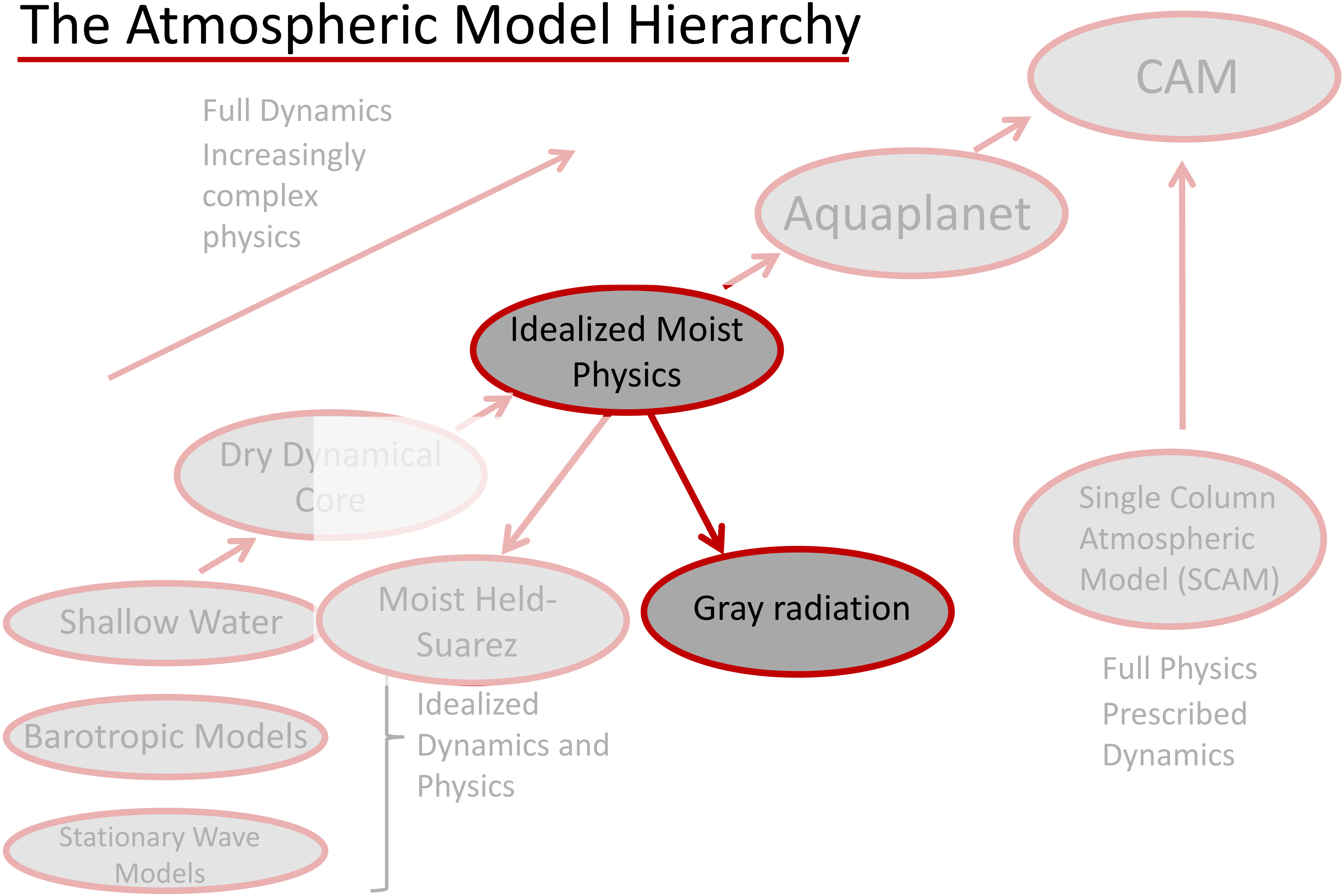

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Prescribed SST

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)

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Mixed layer ocean

Idealized representation of boundary layer fluxes of heat and moisture

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Diabatic heating from condensation of saturated air parcels.

Gray radiation (Frierson et al 2006)

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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.

Gray radiation.

Specified long wave absorber distribution

Radiation does not see water vapor

No clouds

Simplified Monin-Obhukov for surface fluxes

$$\mathcal{T} = \rho_a C |\mathbf{v}_a| \mathbf{v}_a$$

$$S = \rho_a c_p C |\mathbf{v}_a| (\Theta_a - \Theta_s)$$

$$E = \rho_a C |\mathbf{v}_a| (q_a - q_s^*),$$

$$C = \kappa^2 \left(\ln \frac{z_a}{z_0} \right)^{-2} \quad \text{for} \quad \mathrm{Ri}_a < 0 \qquad (12)$$

$$C = \kappa^2 \left(\ln \frac{z_a}{z_0} \right)^{-2} (1 - \mathrm{Ri}_a/\mathrm{Ri}_c)^2 \quad \text{for} \quad 0 < \mathrm{Ri}_a < \mathrm{Ri}_c$$

$$C = 0 \quad \text{for} \quad \mathrm{Ri}_a > \mathrm{Ri}_c,$$

$$\mathrm{Ri}_a = \frac{gz[\Theta_v(z_a) - \Theta_v(0)]/\Theta_v(0)}{|v(z_a)|^2}$$

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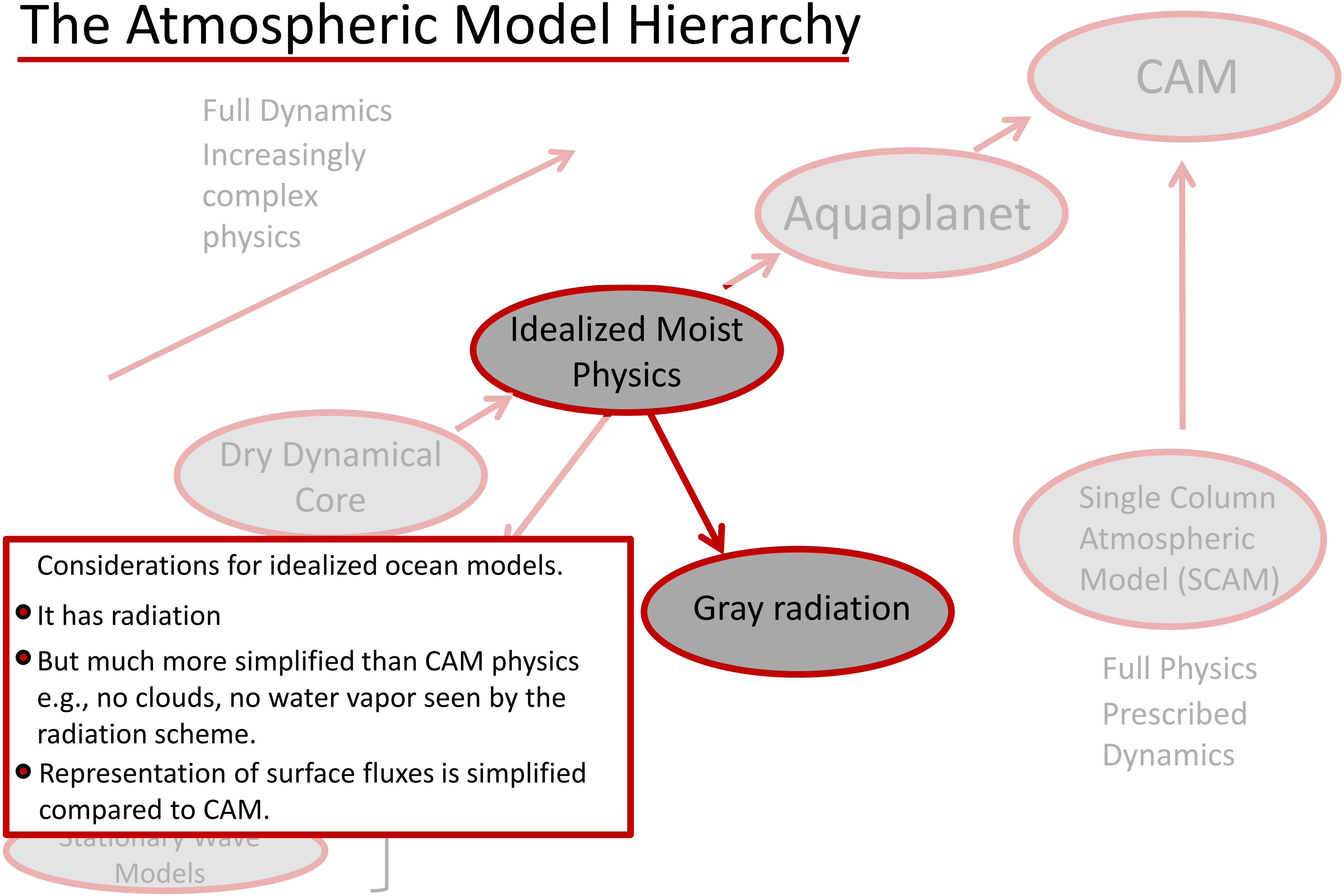
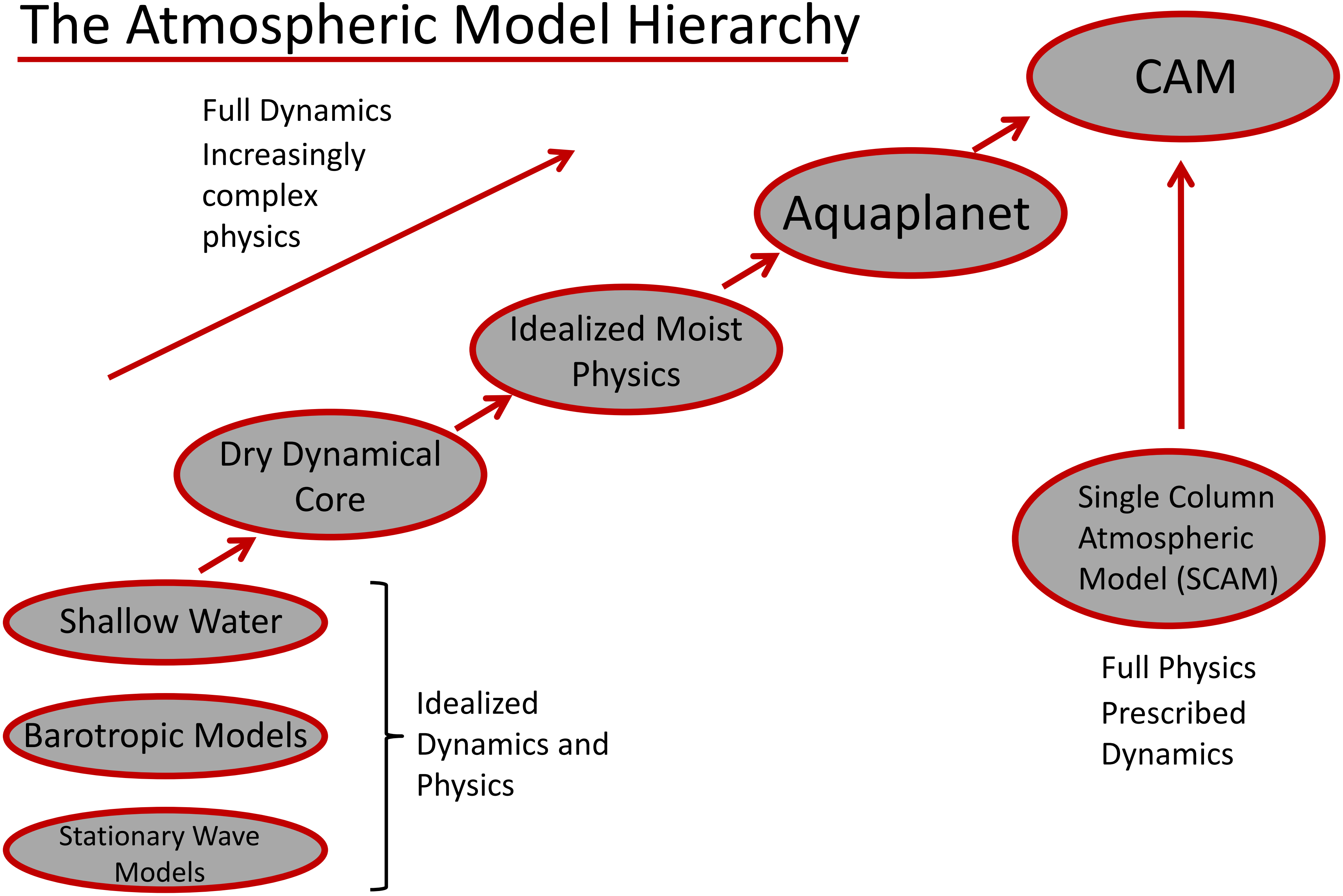


Considerations for idealized ocean models.

- 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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Barotropic Models

Stationary Wave Models

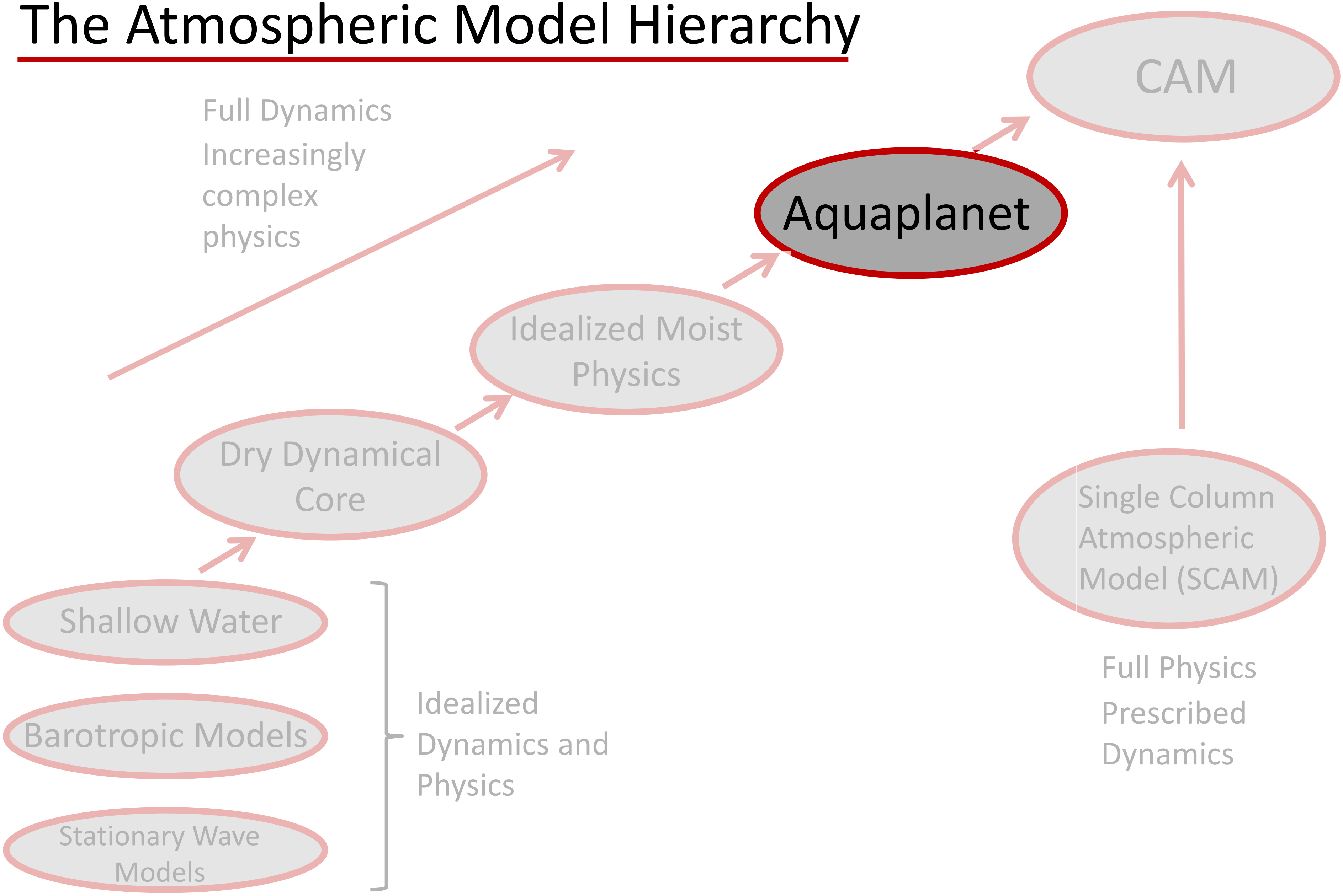
Idealized Dynamics and Physics

Single Column Atmospheric Model (SCAM)

Full Physics

Prescribed Dynamics

The Atmospheric Model Hierarchy



CAM

Full Dynamics
Increasingly complex physics

Aquaplanet

Idealized Moist Physics

Dry Dynamical Core

Single Column Atmospheric Model (SCAM)

Shallow Water

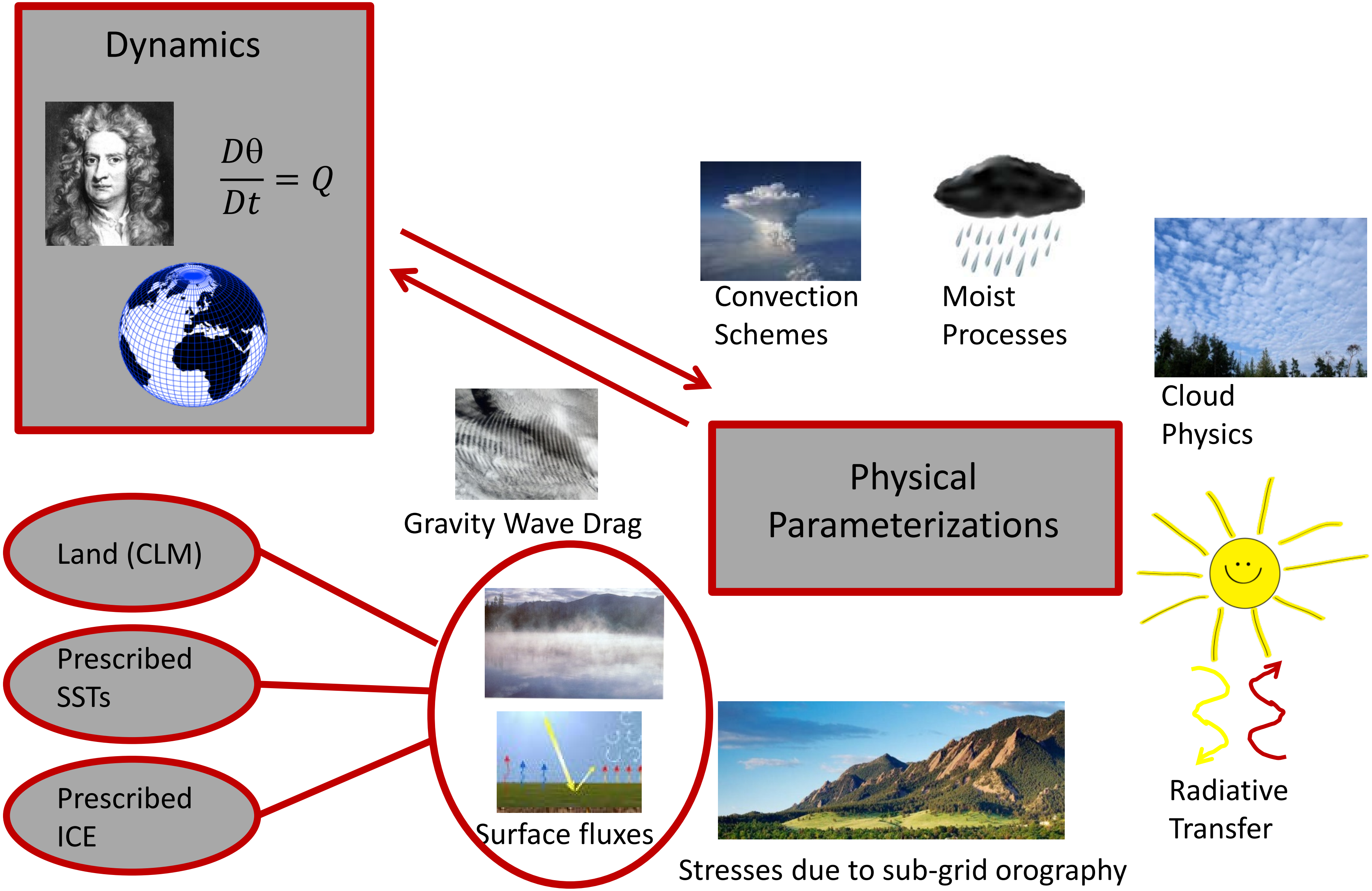
Barotropic Models

Stationary Wave Models

Idealized Dynamics and Physics

Full Physics
Prescribed Dynamics

The Community Atmosphere Model (CAM)



Dynamics

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

Physical Parameterizations

Convection Schemes

Moist Processes

Cloud Physics

Radiative Transfer

Gravity Wave Drag

Stresses due to sub-grid orography

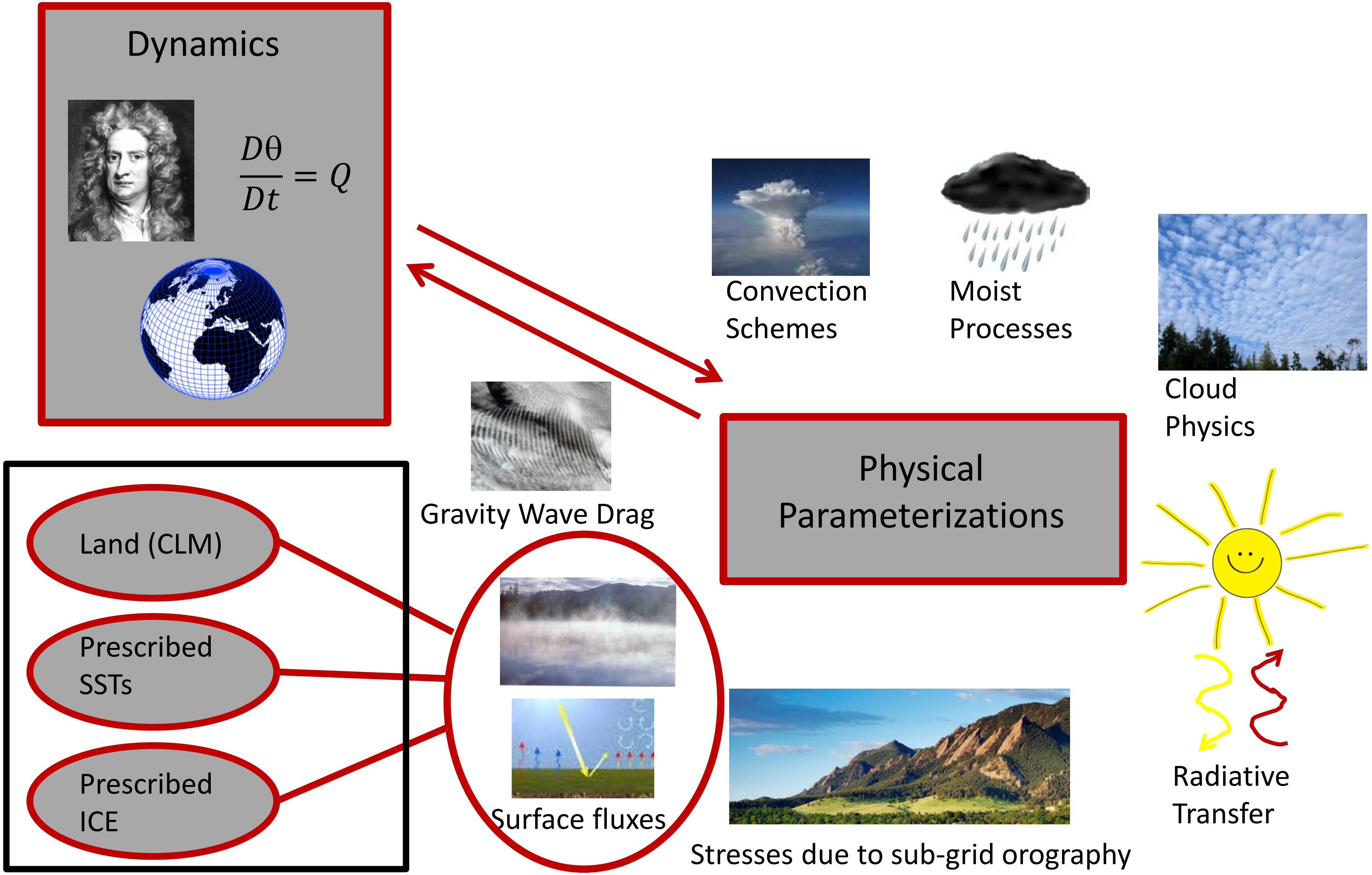
Surface fluxes

Land (CLM)

Prescribed SSTs

Prescribed ICE

The Community Atmosphere Model (CAM)



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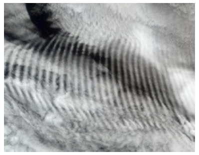
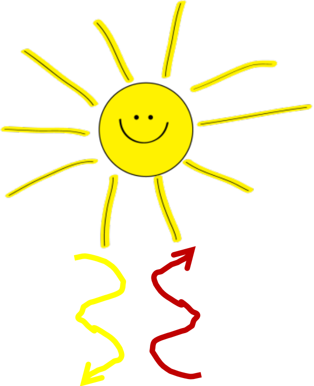


Gravity Wave Drag

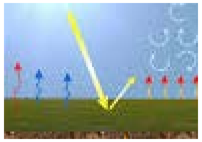
Physical Parameterizations



Radiative Transfer

Water covered Earth

Slab ocean or prescribed SST



Surface fluxes

Stresses due to sub-grid orography

The Community Atmosphere Model (CAM)

Dynamics

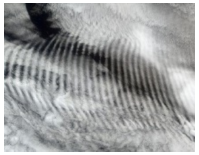
$$\frac{D\theta}{Dt} = Q$$

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

Convection Schemes

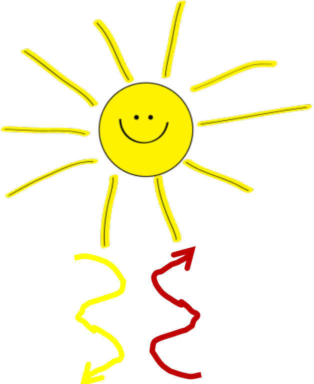
Moist Processes

Cloud Physics



Gravity Wave Drag

Physical Parameterizations



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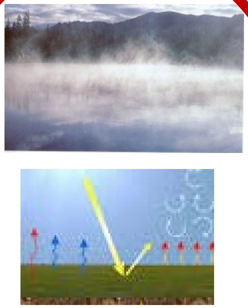

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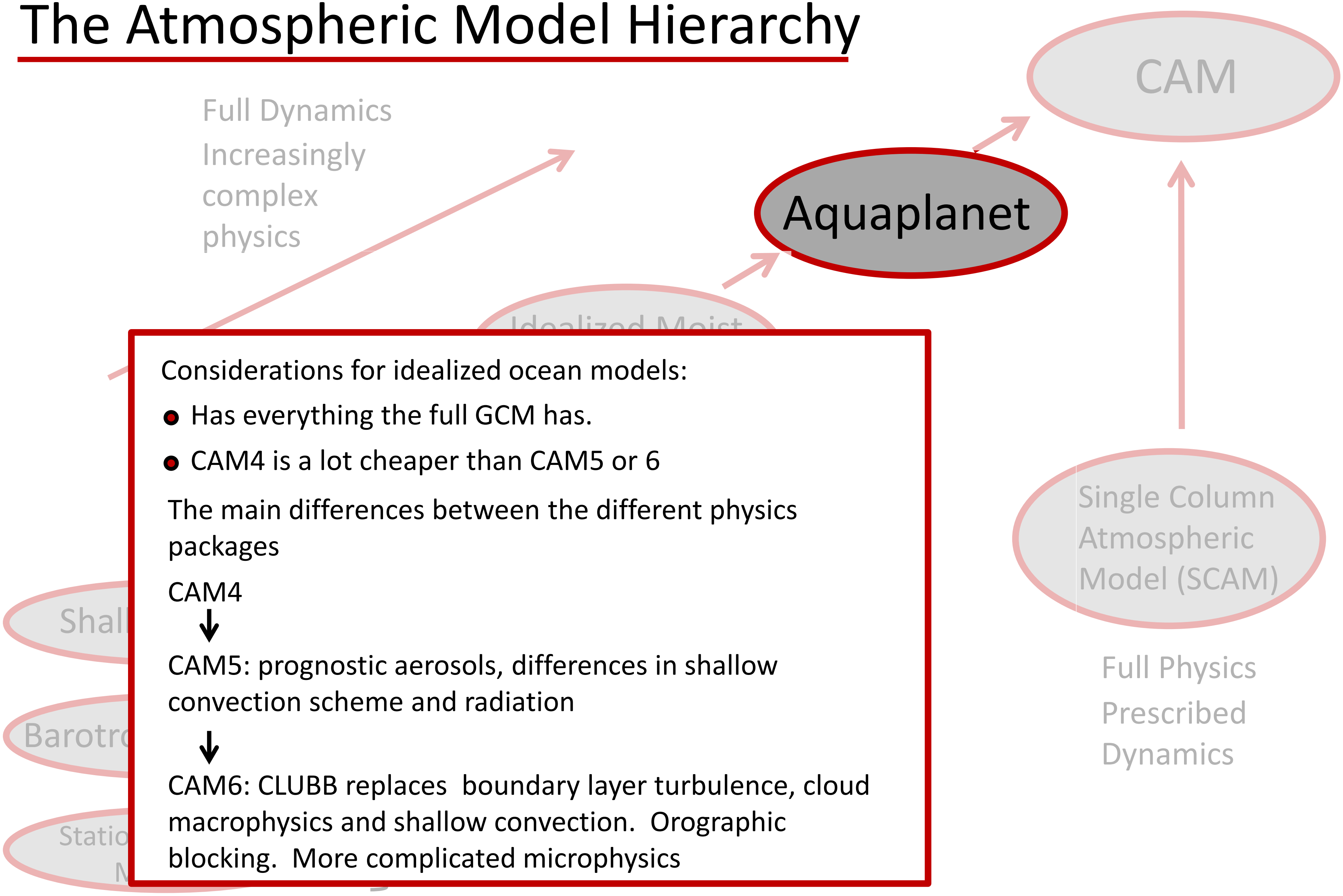
The Atmospheric Model Hierarchy



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

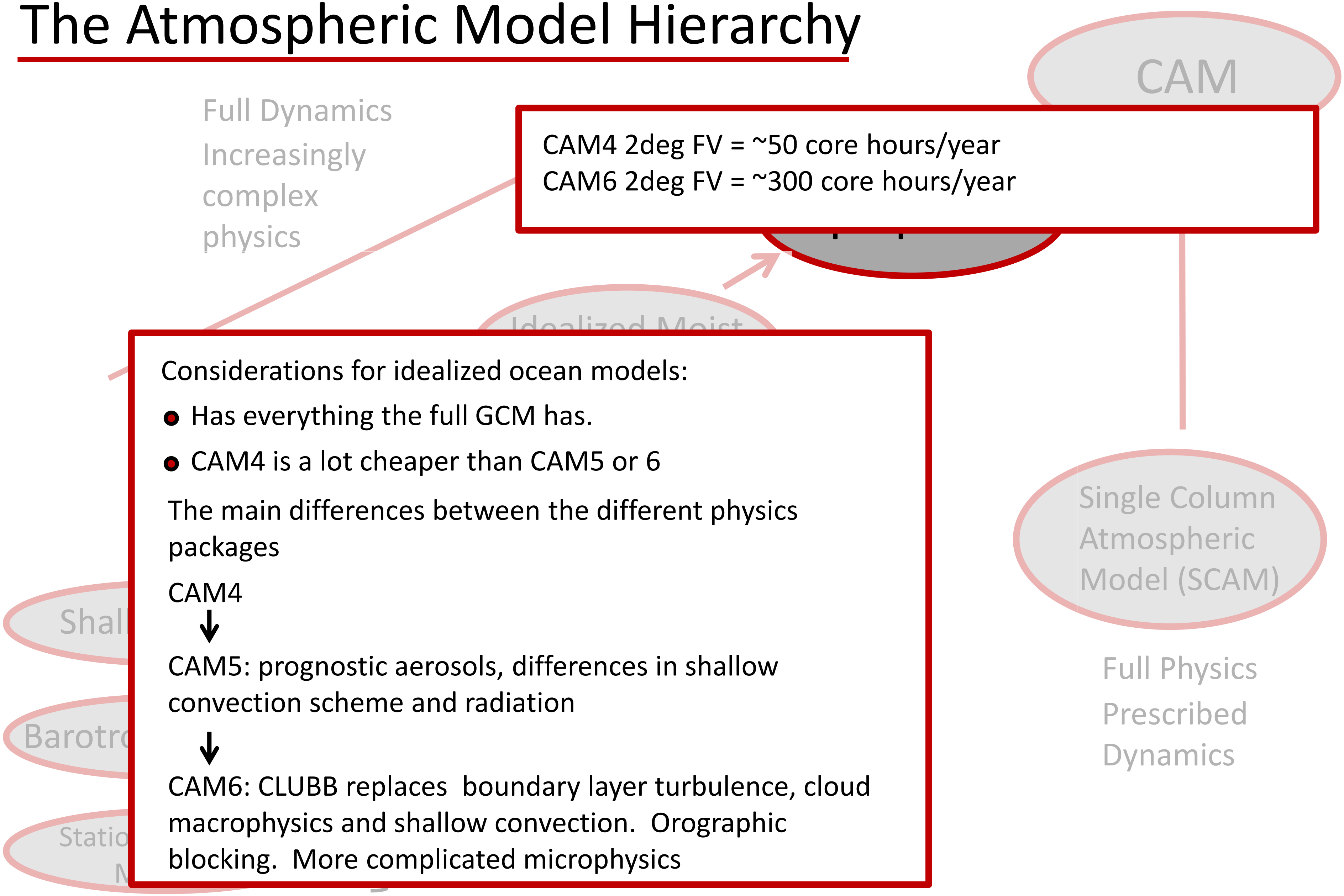
↓

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

The Atmospheric Model Hierarchy



CAM4 2deg FV = ~50 core hours/year
CAM6 2deg FV = ~300 core hours/year

Considerations for idealized ocean models:

- Has everything the full GCM has.
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The main differences between the different physics packages

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↓

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

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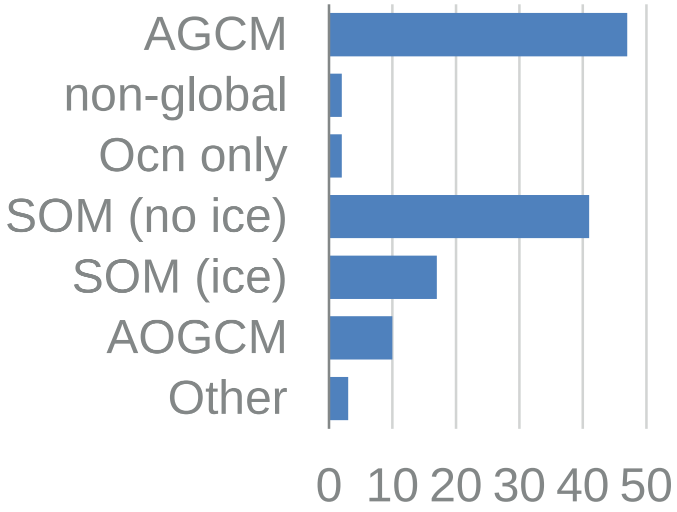
CAM6: CLUBB replaces boundary layer turbulence, cloud macrophysics and shallow convection. Orographic blocking. More complicated microphysics

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