Idealized modelling within the CESM framework

Many contributors (in alphabetical order): Alper Altuntas, Scott Bachman, Jim Benedict, Patrick Callaghan, Cheryl Craig, Gokhan Danabasoglu, Brain Dobbins, Brian Eaton, Andrew Gettelman, Steve Goldhaber, Christiane Jablonowski, Erik Kluzek Marysa Lague, Jean-Francois Lamarque, Peter Lauritzen, Sam Levis, Brian Medeiros, Kevin Reed, Bill Sacks, Isla Simpson, John Truesdale, Marana Vertenstein, Colin Zarzycki

NCAR

NSF

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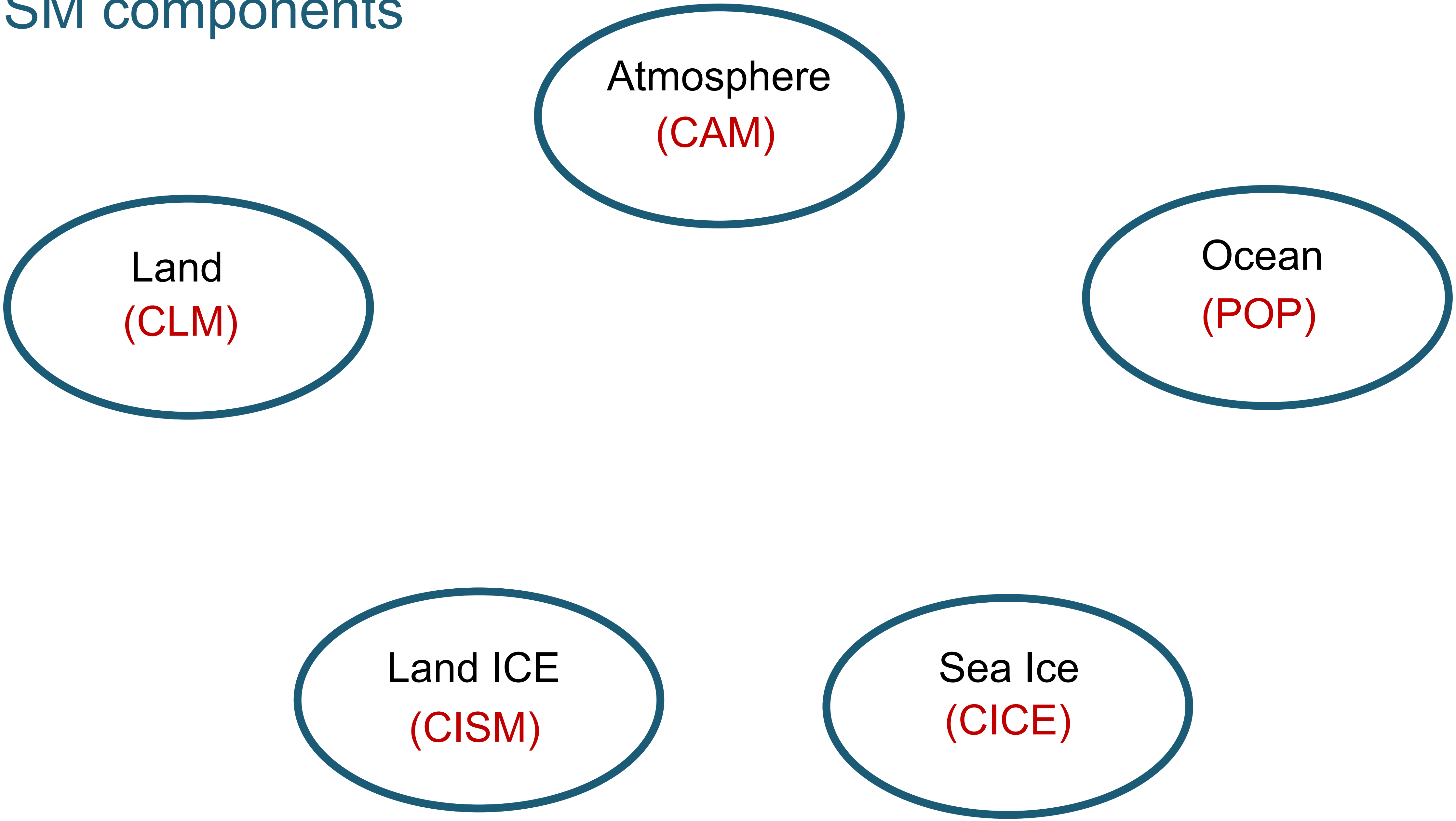
CESM components



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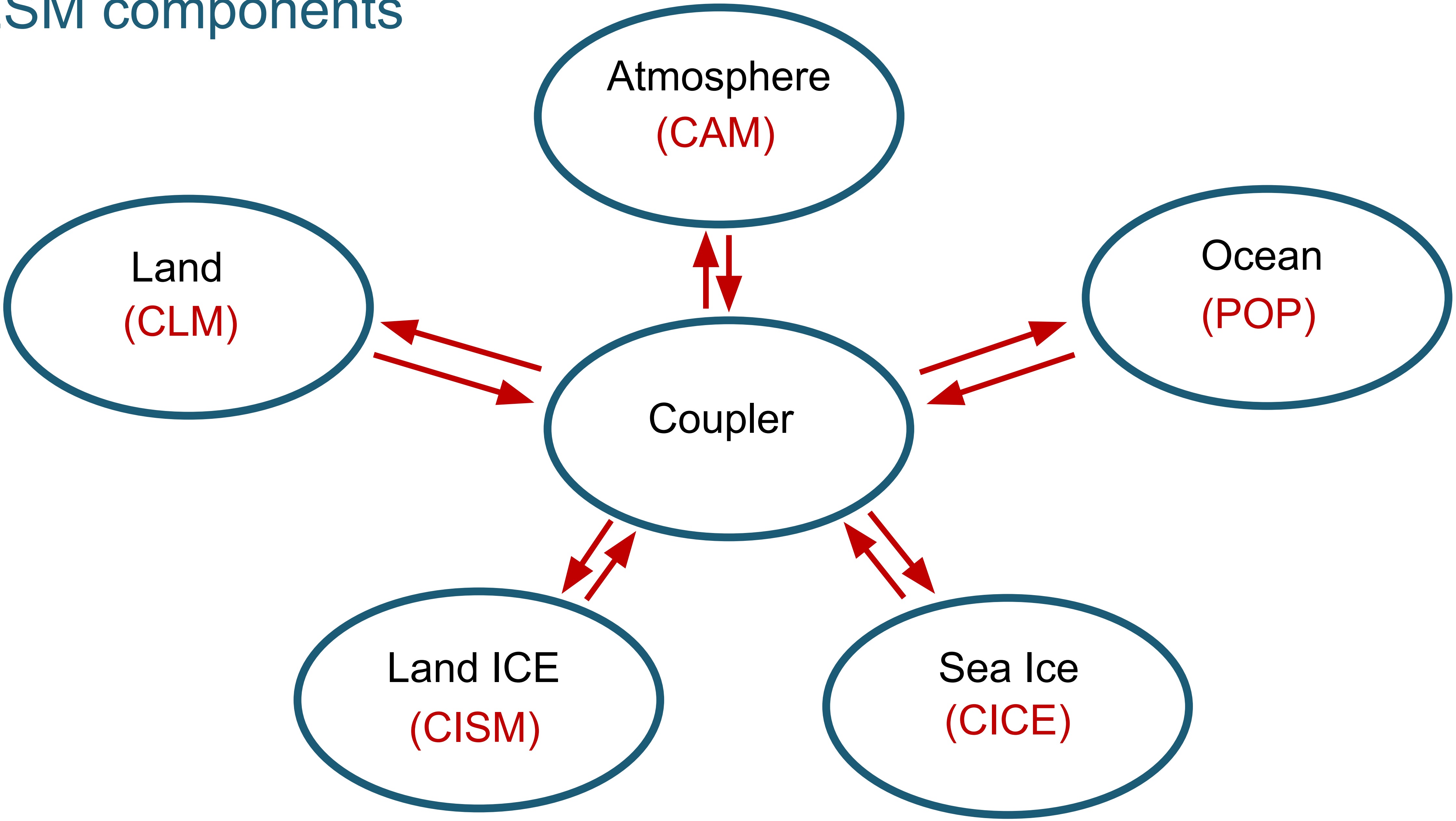

Atmosphere

(CAM)

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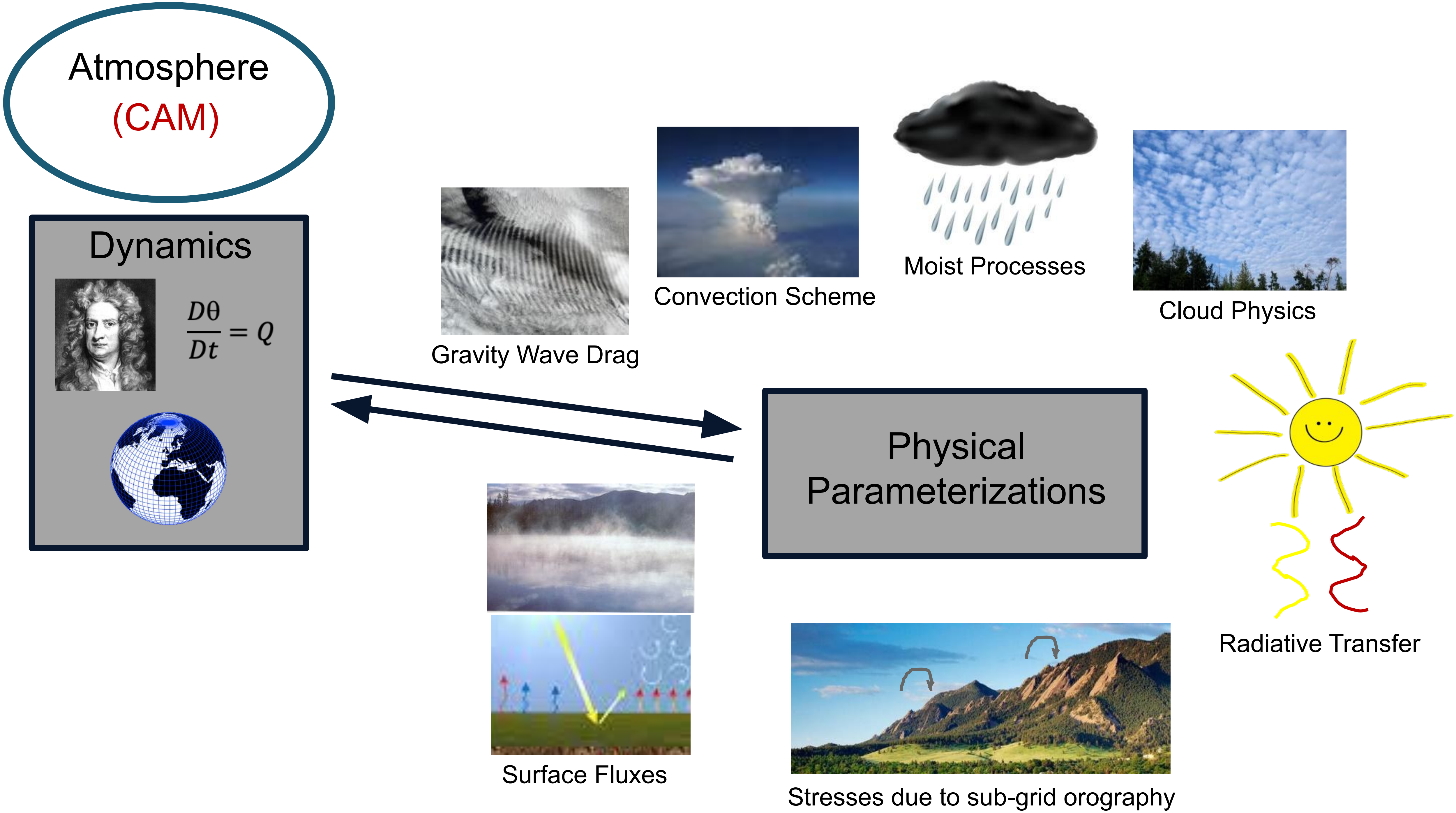
(CAM)

Dynamics

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


Atmosphere
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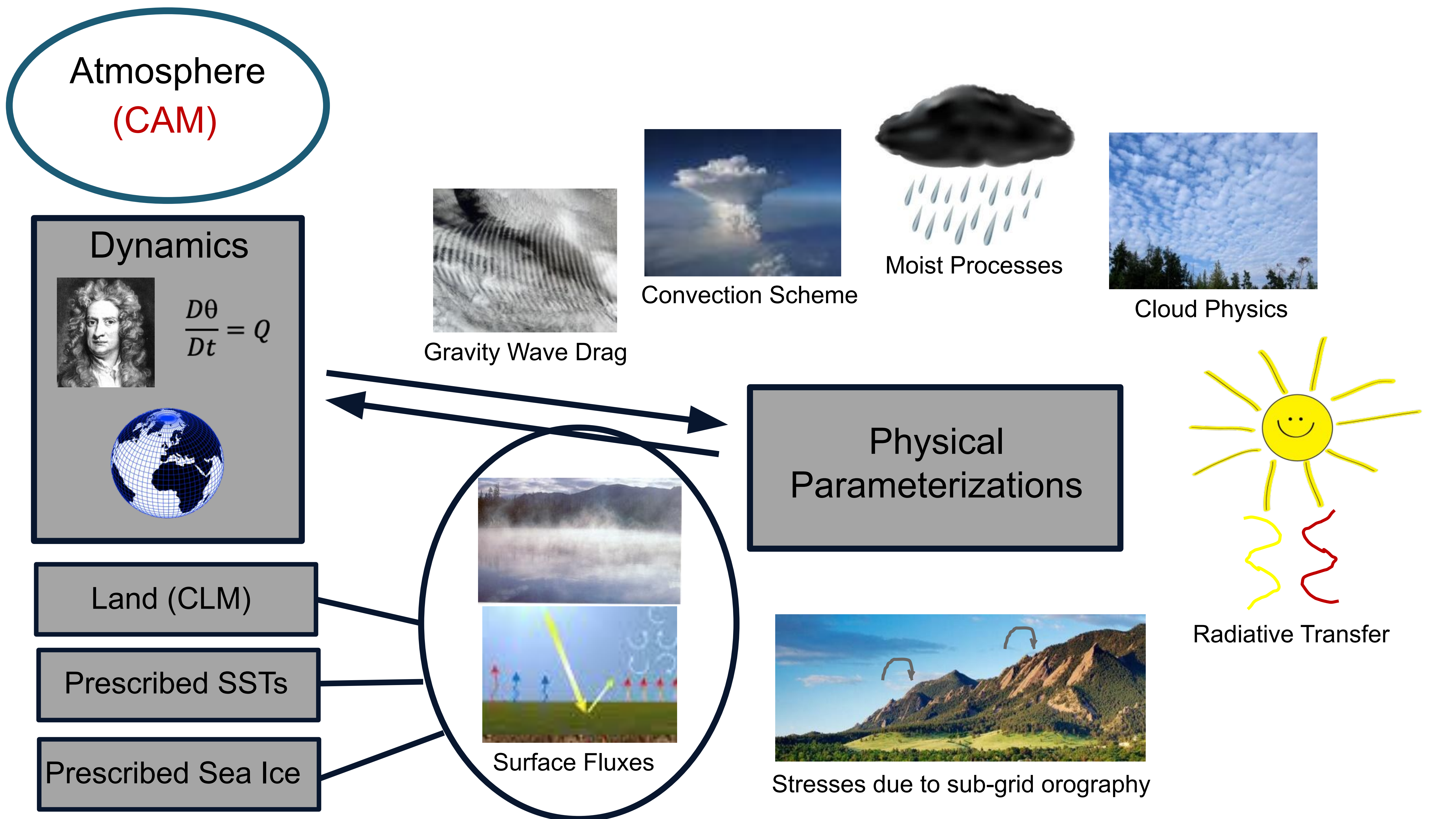
Gravity Wave Drag
Convection Scheme
Moist Processes
Cloud Physics
Physical Parameterizations
Radiative Transfer
Surface Fluxes
Stresses due to sub-grid orography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Land (CLM)
Prescribed SSTs
Prescribed Sea Ice
Surface Fluxes
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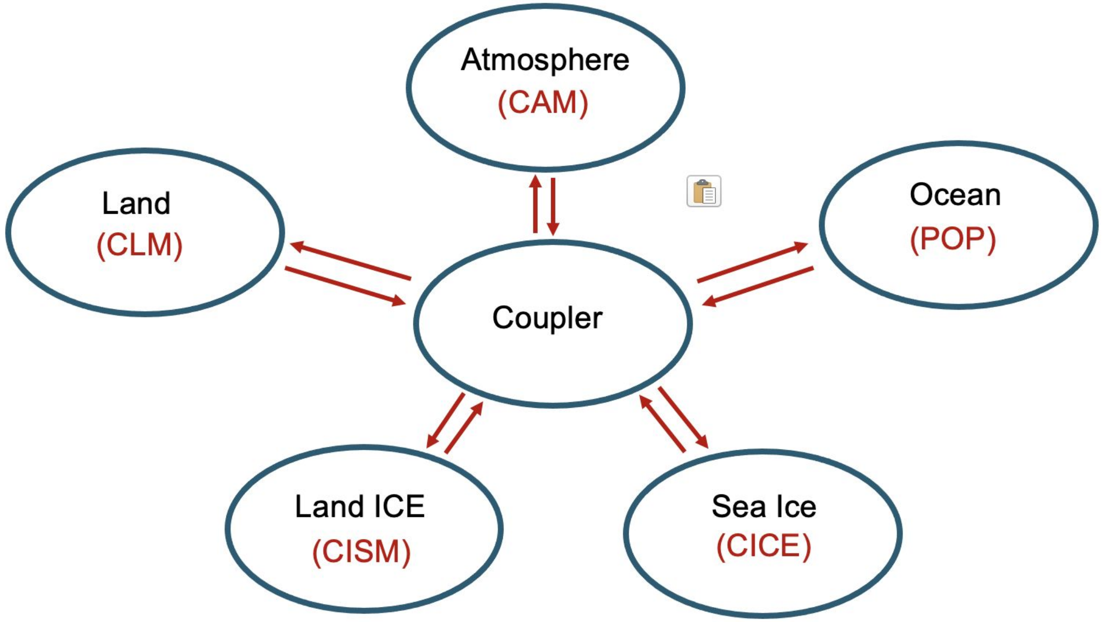
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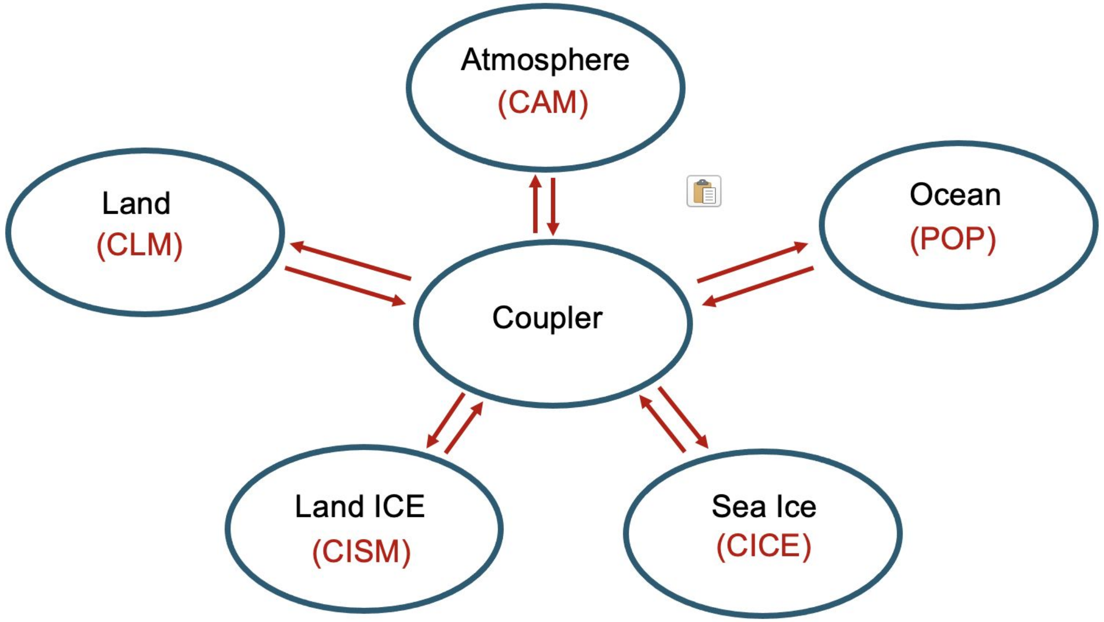
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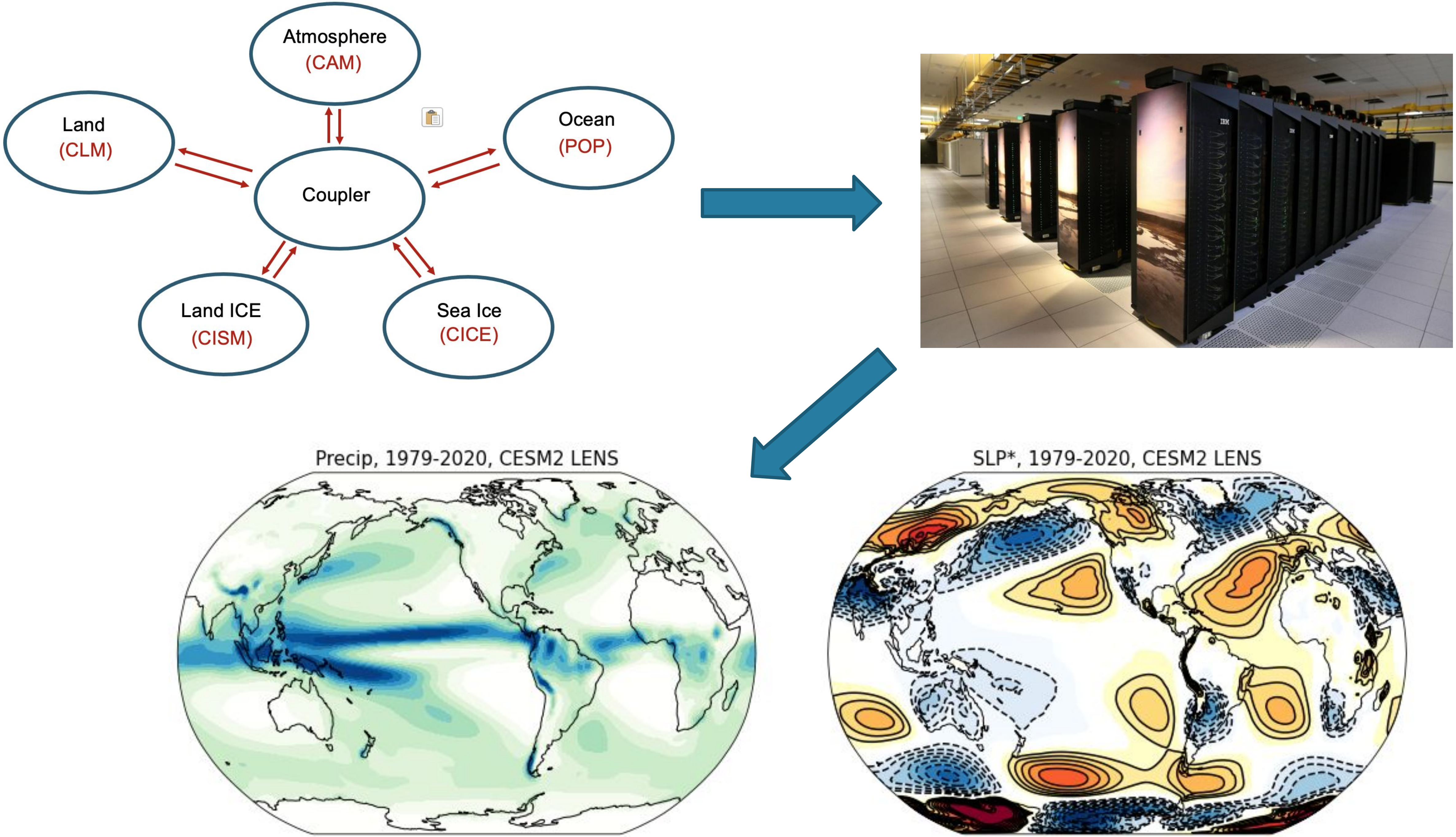
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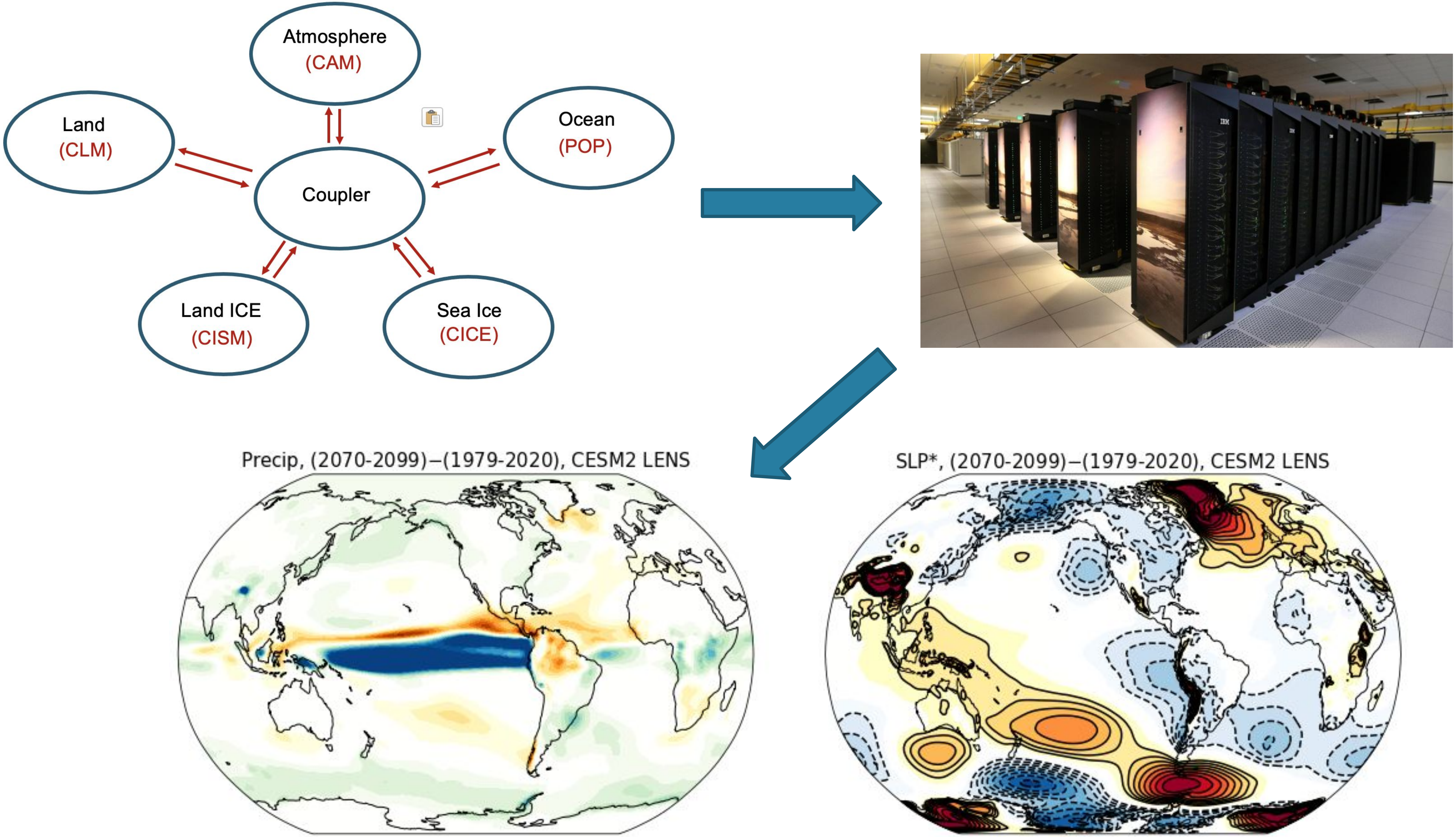
Precip, 1979-2020, CESM2 LENS
SLP*, 1979-2020, CESM2 LENS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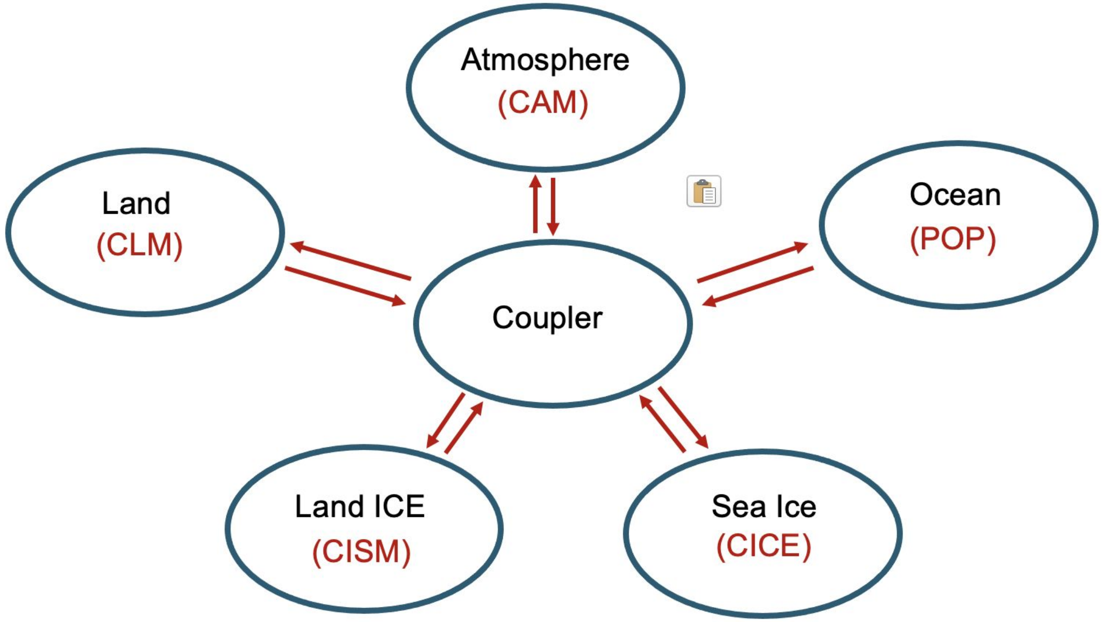
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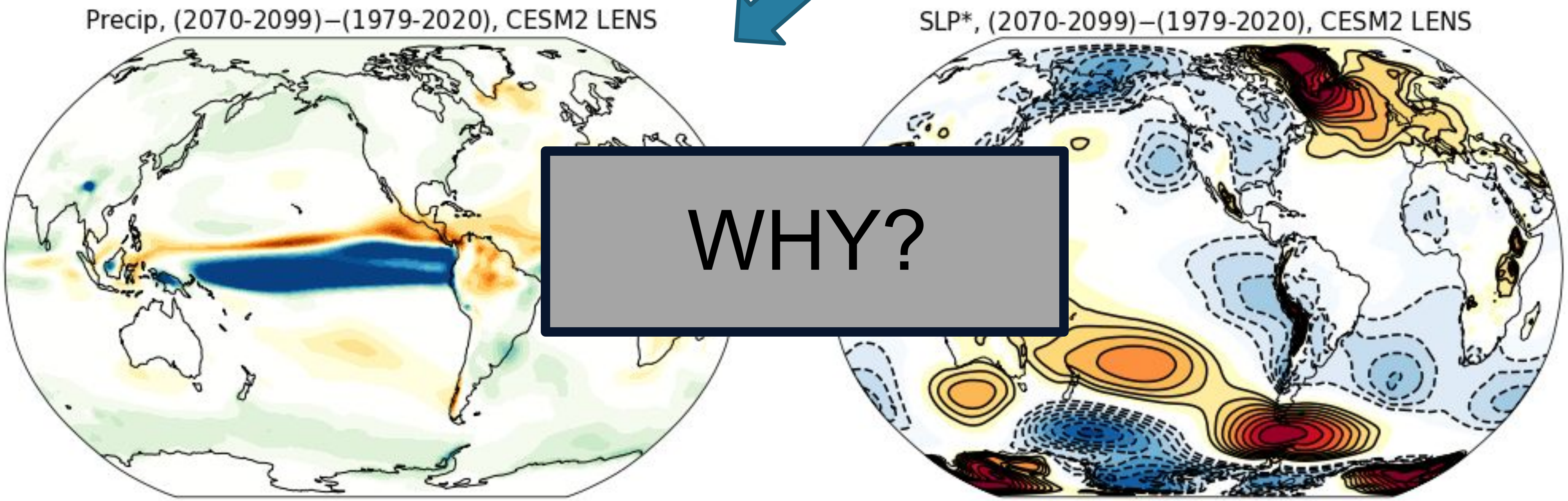
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WHY?

Problems

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- CESM is complicated. Everything is changing all at once

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- All components are strongly coupled and interacting to ensure these balances are maintained. One thing changes, everything else responds, making it hard to establish causal relationships.
- To obtain the solution we had to use a large supercomputer speaks to the complexity of the processes involved.

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The capacity to run idealized models within CESM is growing

Simpler models website: https://www.cesm.ucar.edu/models/simple

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…stripped down versions of CESM that only contain certain components and/or idealized representation of certain components.

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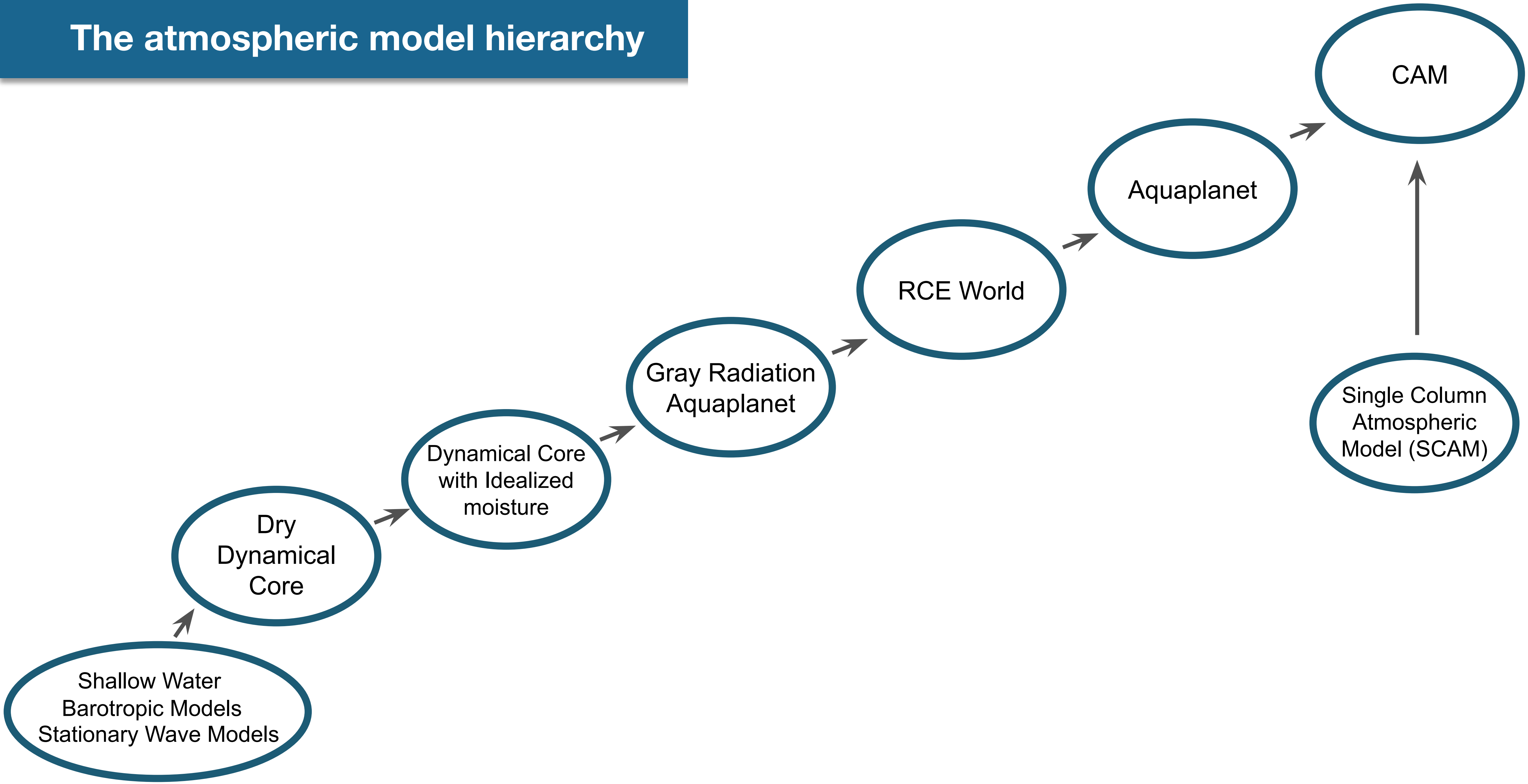
Always keep your eye on the real world/full CESM

Atmospheric Simpler Models

The atmospheric model hierarchy



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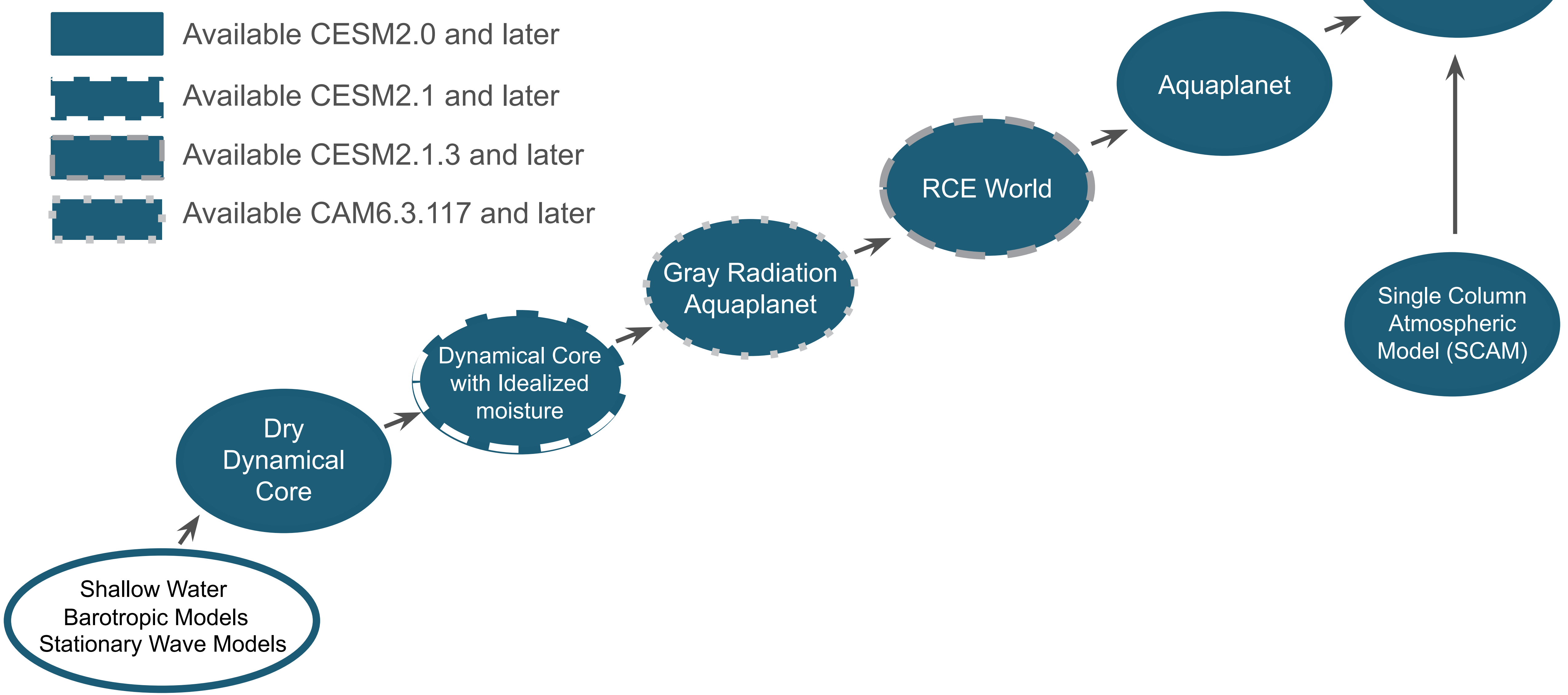

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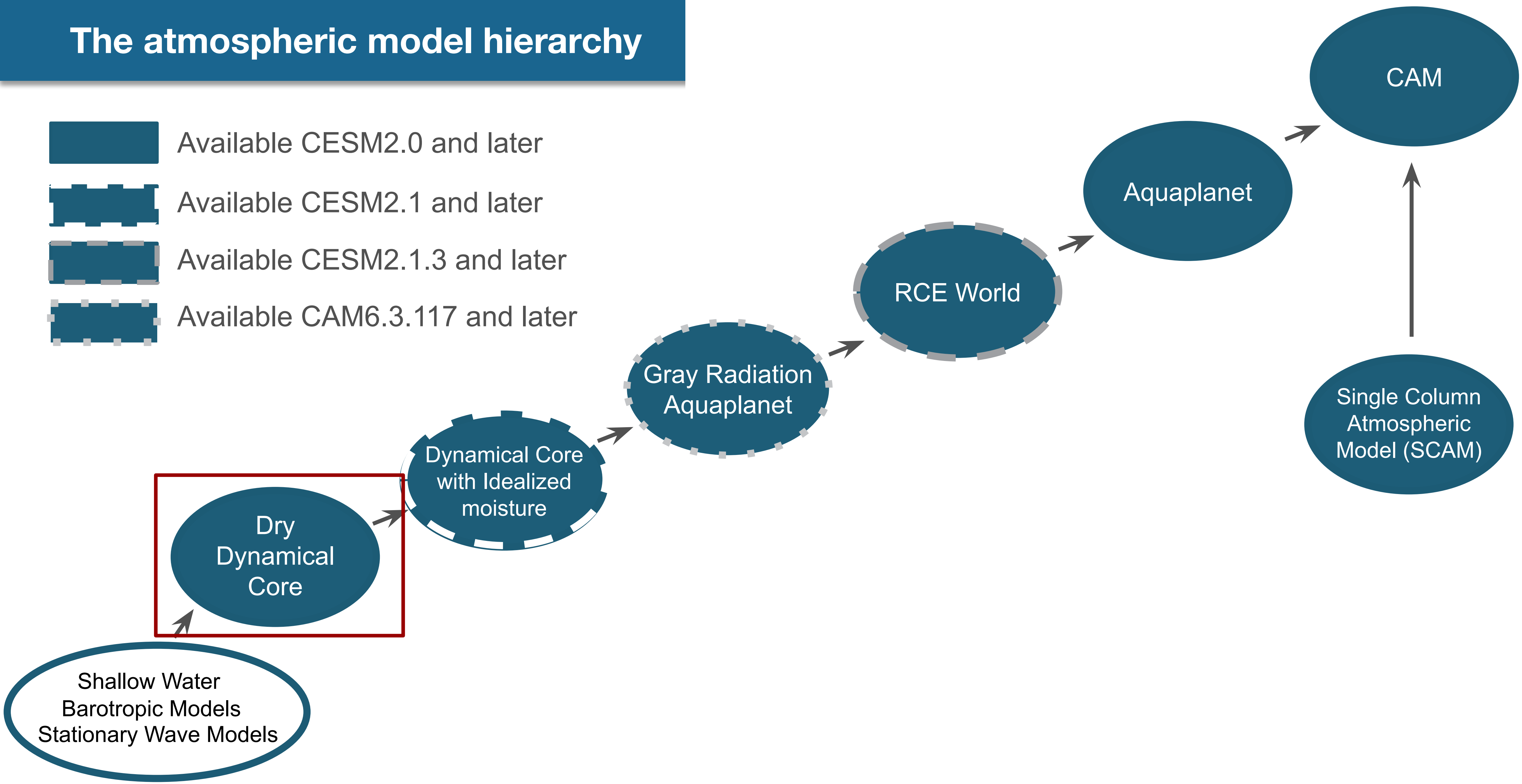

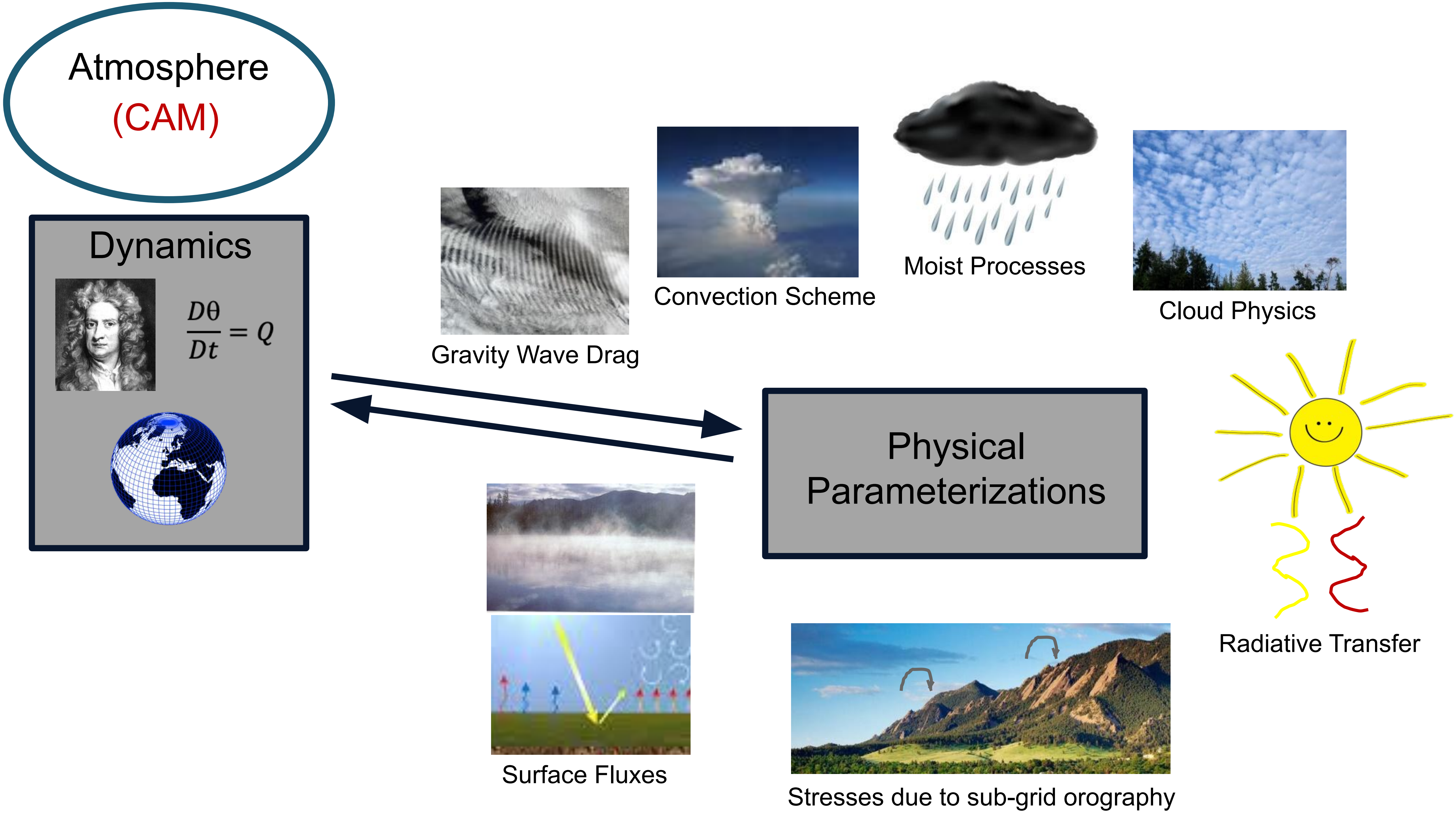

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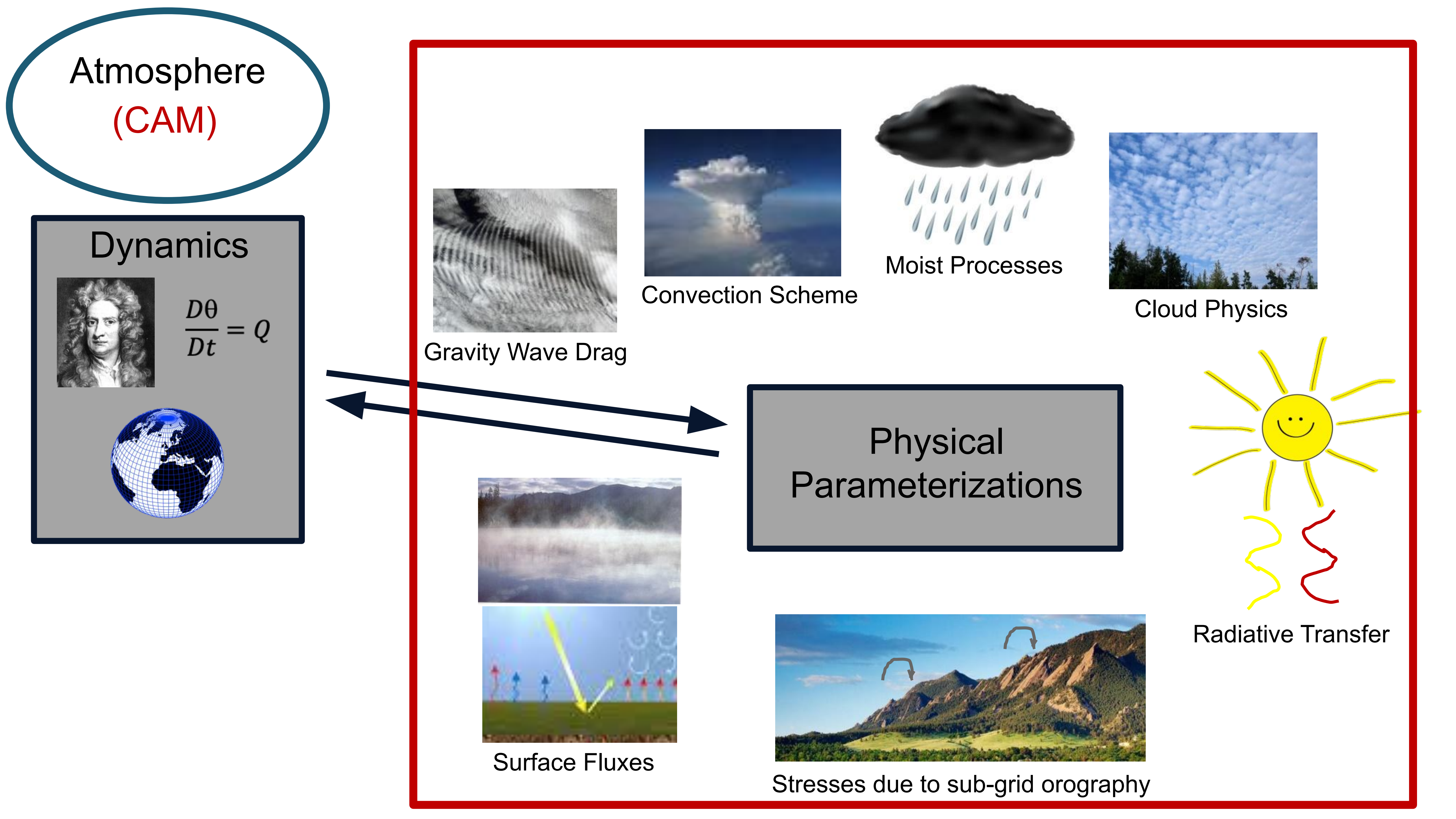
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Newtonian relaxation of the temperature field toward a specified equilibrium profile

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

Linear drag on wind at the lowest levels

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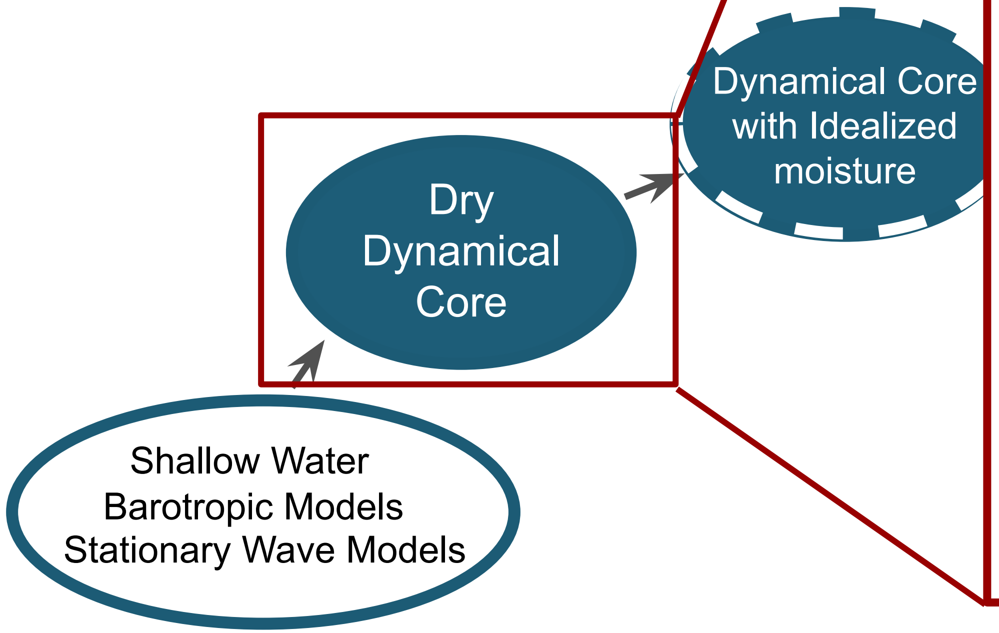
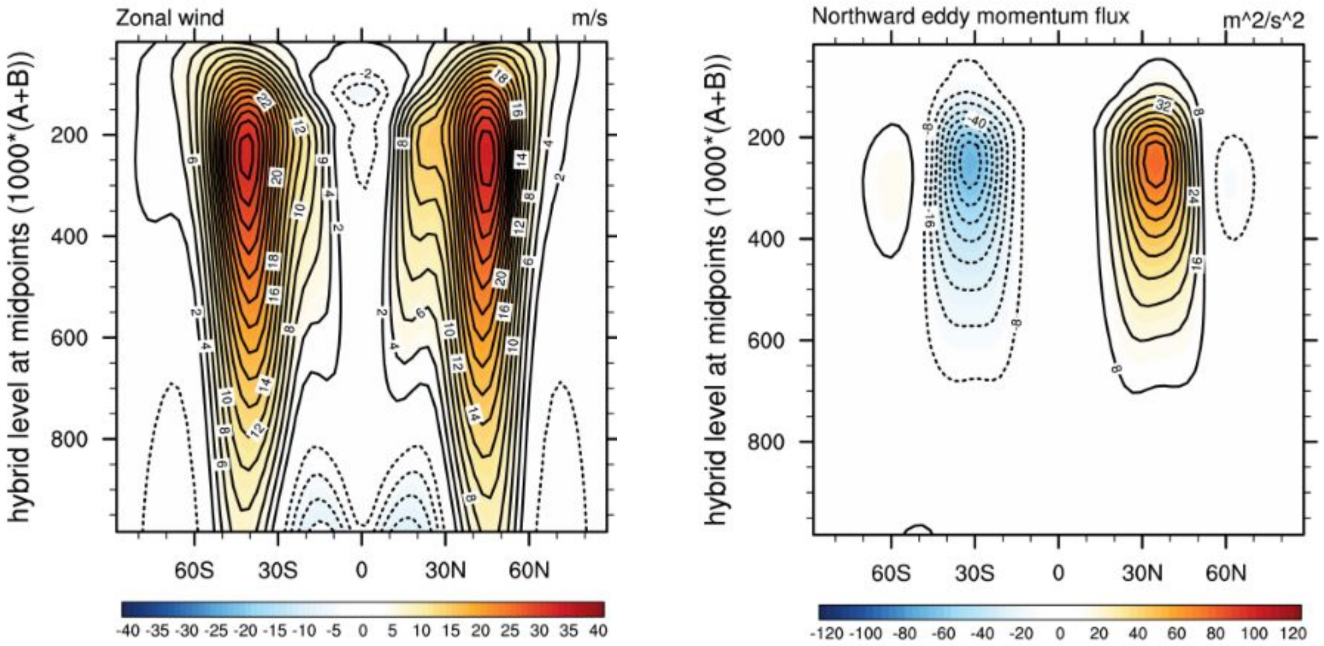


Dry Dynamical Core: https://www.cesm.ucar.edu/models/simple/held-suarez

All physical parameterizations replaced by Newtonian relaxation of the temperature field toward a zonally symmetric equilibrium temperature profile and linear drag on the near surface winds, following Held and Suarez (1994).

Currently runs with all dynamical cores (Eulerian, Finite Volume, Spectral Element, MPAS, FV3)

Good for dry dynamics. Can easily perturb the temperature



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Dynamical Core with Idealized moisture

Dry Dynamical Core

Shallow Water
Barotropic Models
Stationary Wave Models

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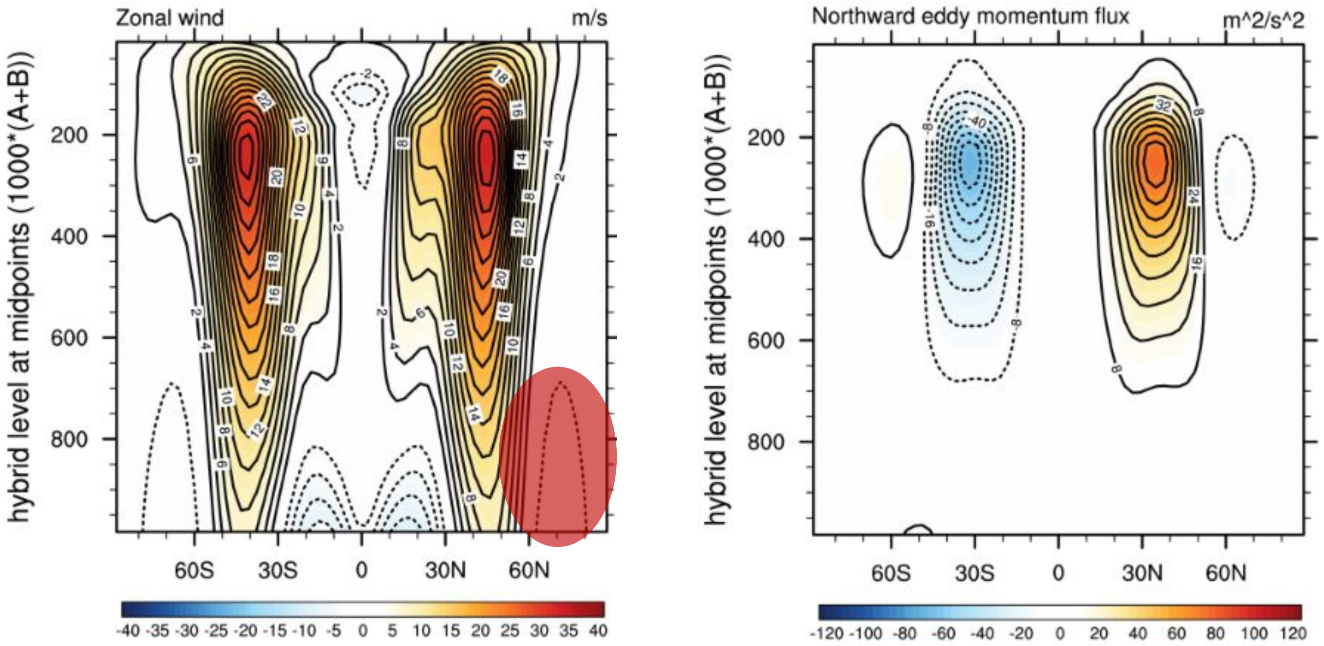

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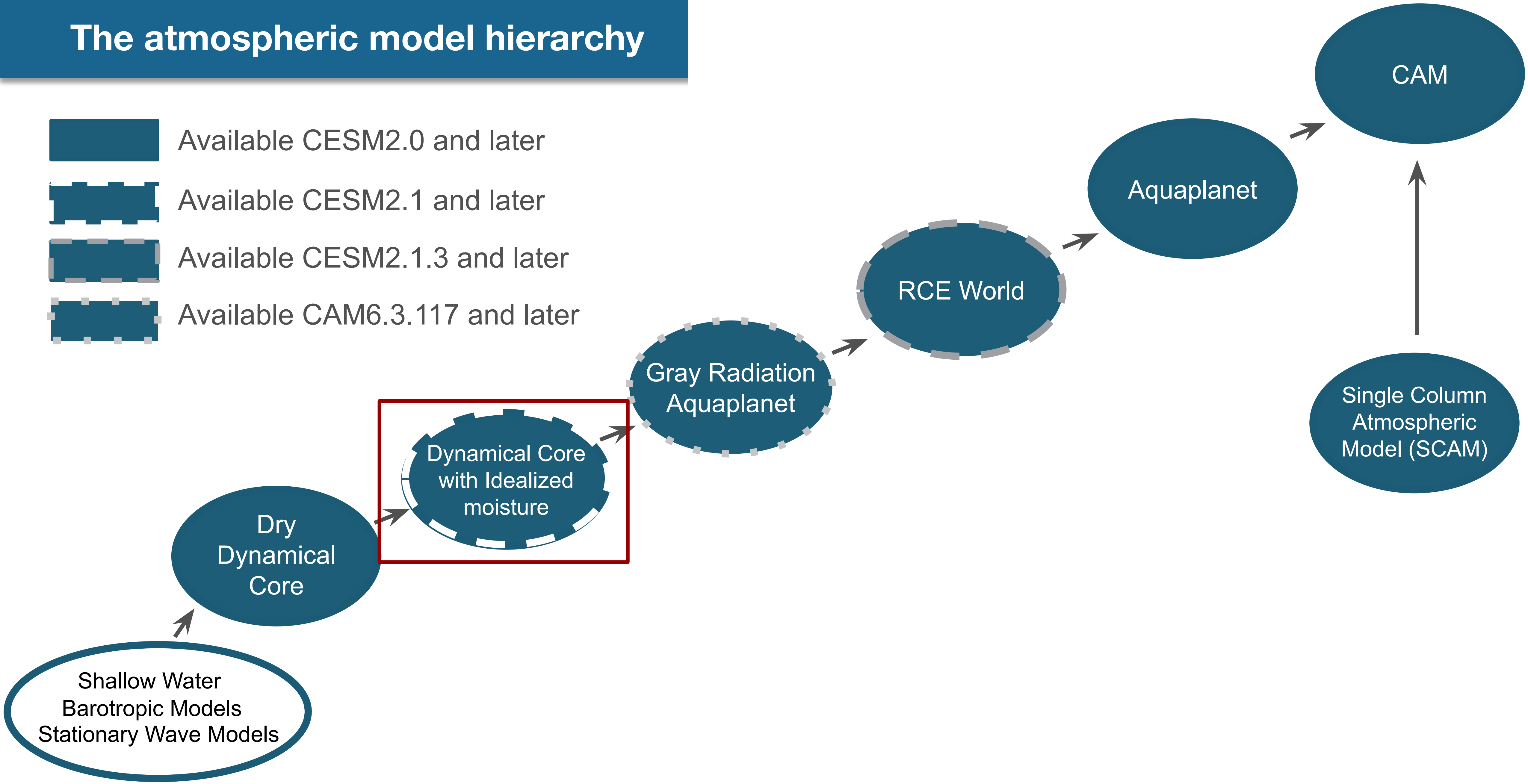

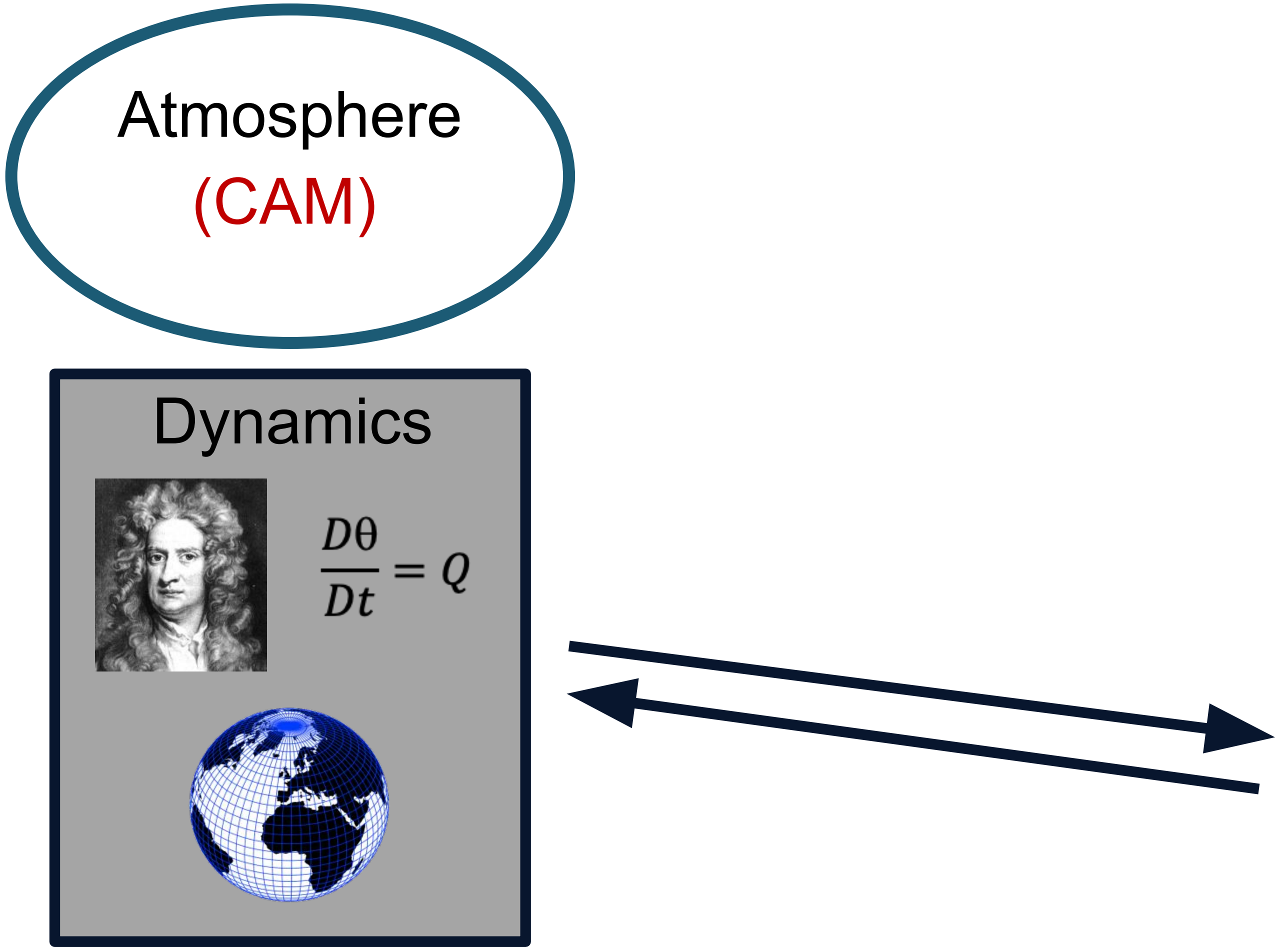

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Water covered Earth

Prescribed SSTs

Evaporation

Heating associated with precipitation

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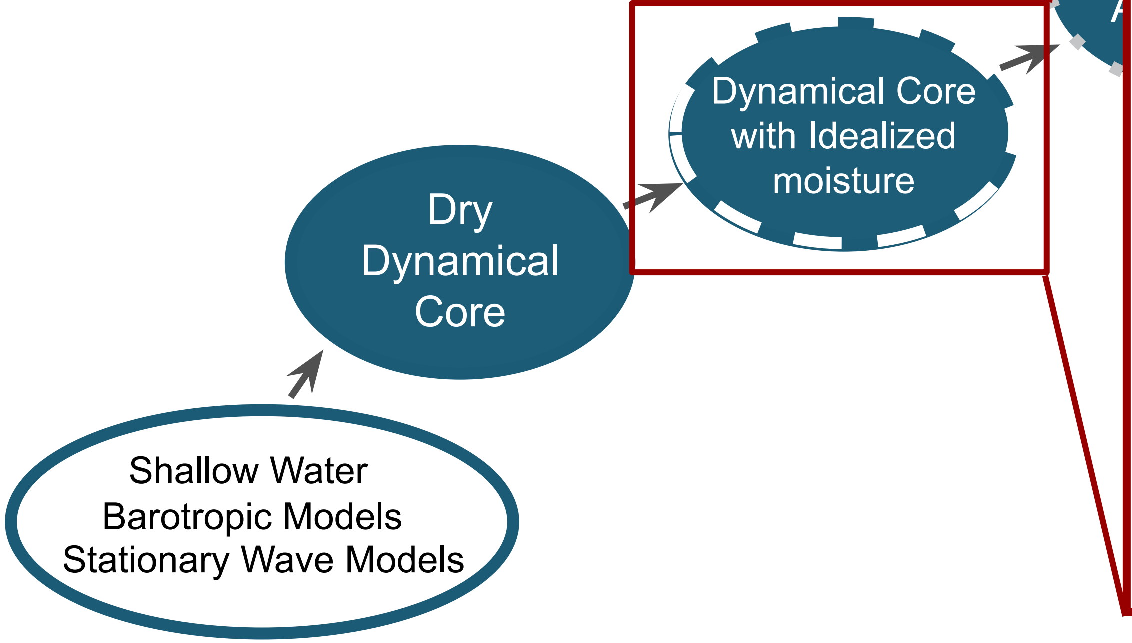


Moist Held-Suarez (Thatcher and Jablonowski 2016):
https://www.cesm.ucar.edu/models/simple/moist-held-suarez

Like the dry dynamical core but with a representation of the large scale condensation of moisture and associated diabatic heating.

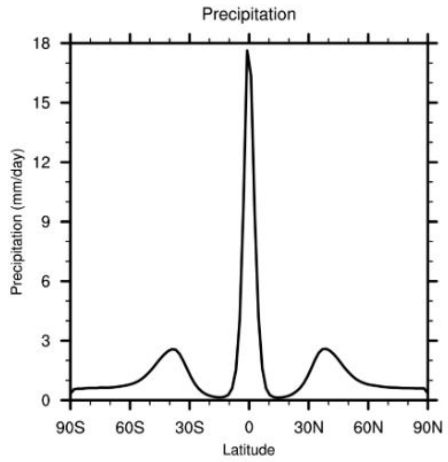
Water covered Earth, prescribed SST profile. Representation of surface sensible and latent heat flux using bulk formulae.

Newtonian relaxation of the temperature field.

Moisture is advected by the large scale circulation, consensus when it reaches saturation and immediately precipitated with an associated diabatic heating.

Good for dynamical studies involving the interaction between moisture and the large scale flow.

Precipitation in moist Held-Suarez



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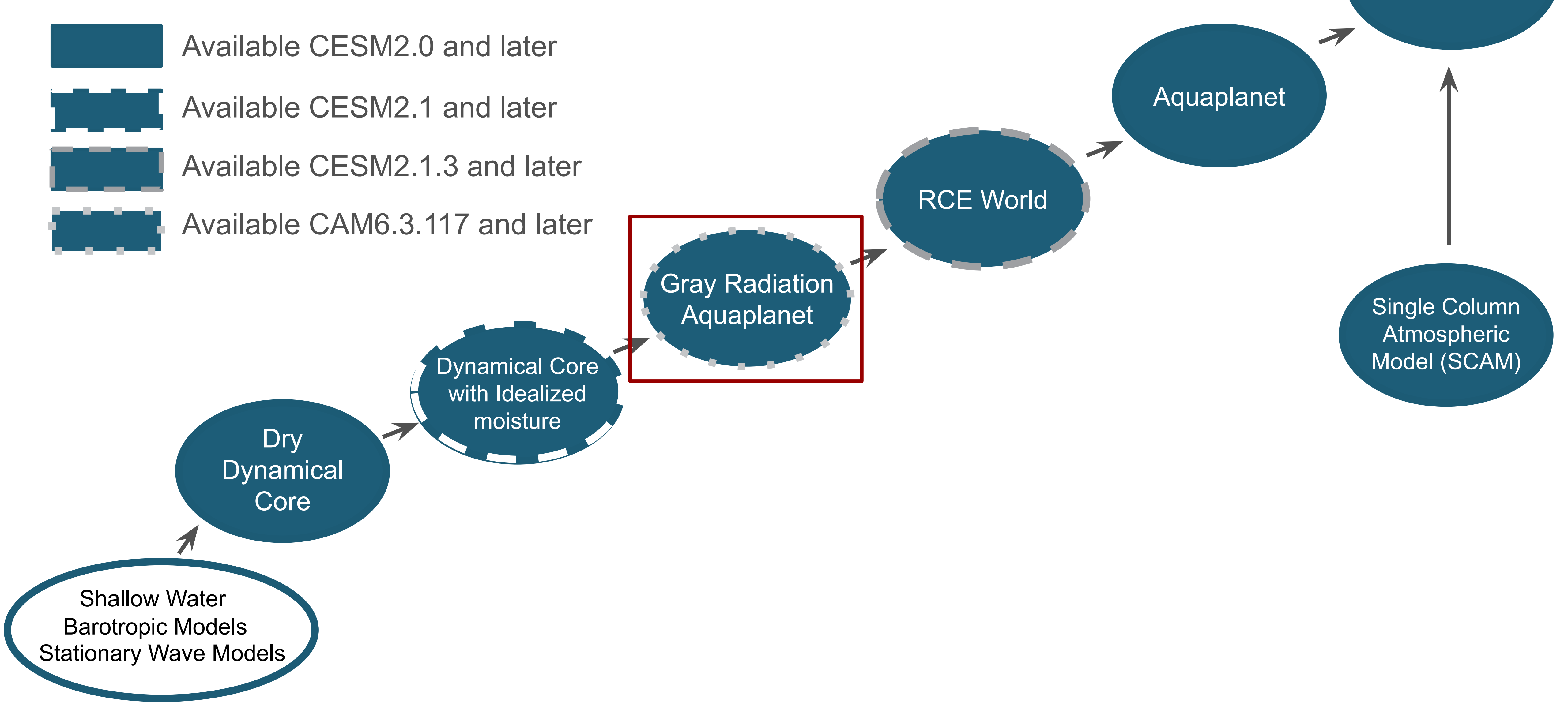

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Water covered Earth

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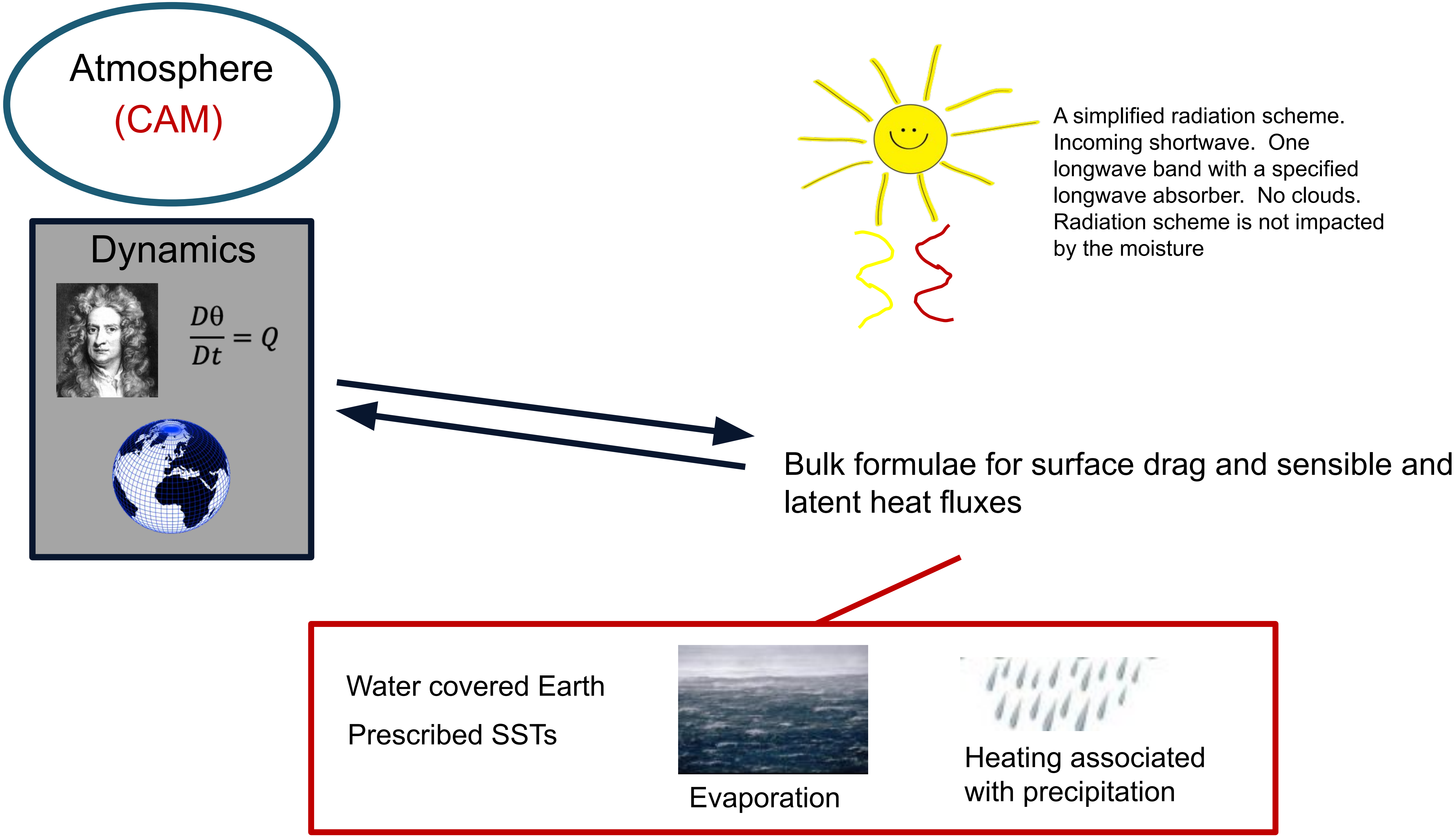

Atmosphere
(CAM)
Dynamics
$\frac{D\theta}{Dt} = Q$
A simplified radiation scheme. Incoming shortwave. One longwave band with a specified longwave absorber. No clouds. Radiation scheme is not impacted by the moisture
Bulk formulae for surface drag and sensible and latent heat fluxes
Water covered Earth
Prescribed SSTs
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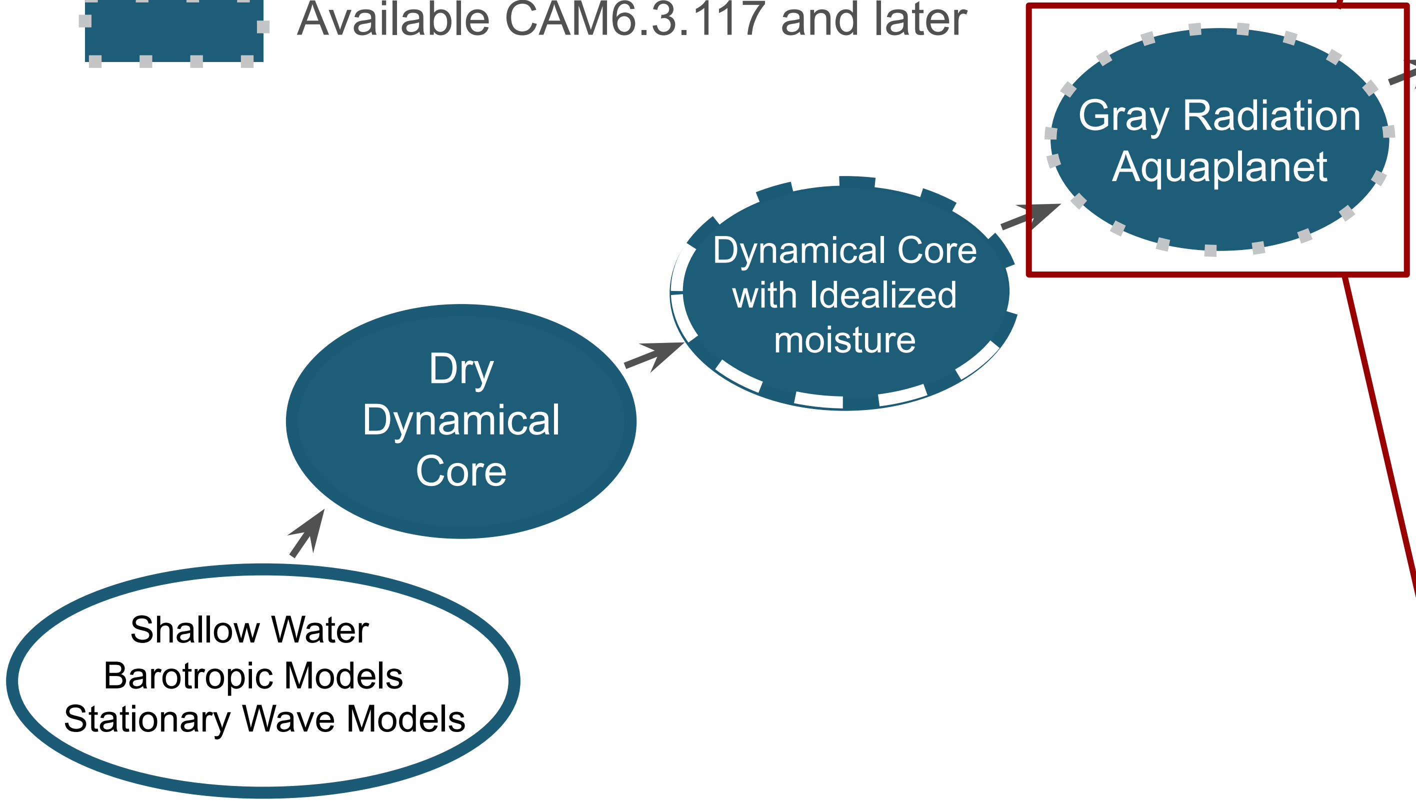


Gray Radiation Aquaplanet (coming soon)

A Gray-Radiation Aquaplanet Moist GCM. Part I: Static Stability and Eddy Scale

Dargan M. W. Frierson

Program in Applied and Computational Mathematics, Princeton University, Princeton, New Jersey

Isaac M. Held

NOAA/GFDL, Princeton, New Jersey

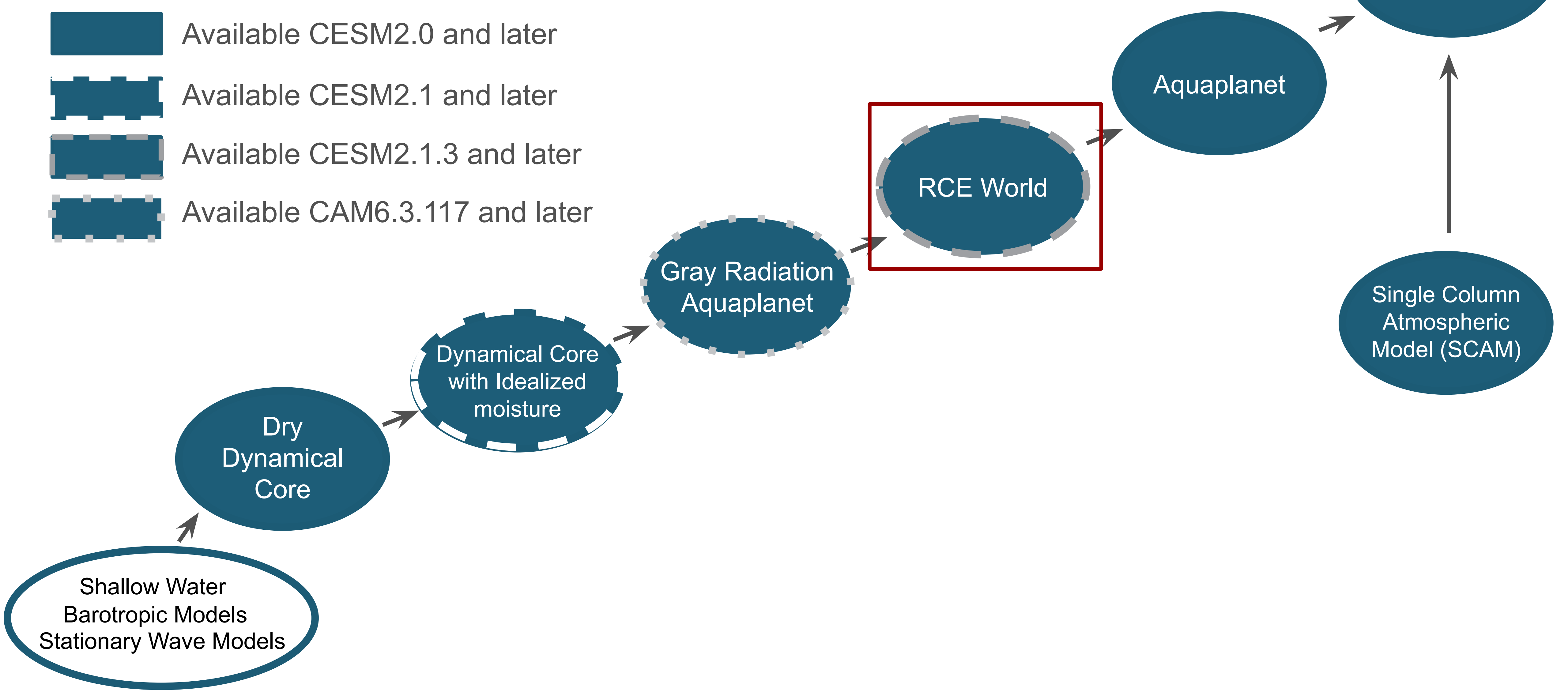
Pablo Zurita-Gotor

UCAR/GFDL, Princeton, New Jersey

- Slab Ocean
- Gray radiative transer
- Specified longwave absorber. Radiation doesn't see water vapor
- No clouds
- Bulk formulae for surface drag, sensible and latent heat fluxes.

Good for idealized studies of the interactions between the circulation and radiation and moisture

The atmospheric model hierarchy

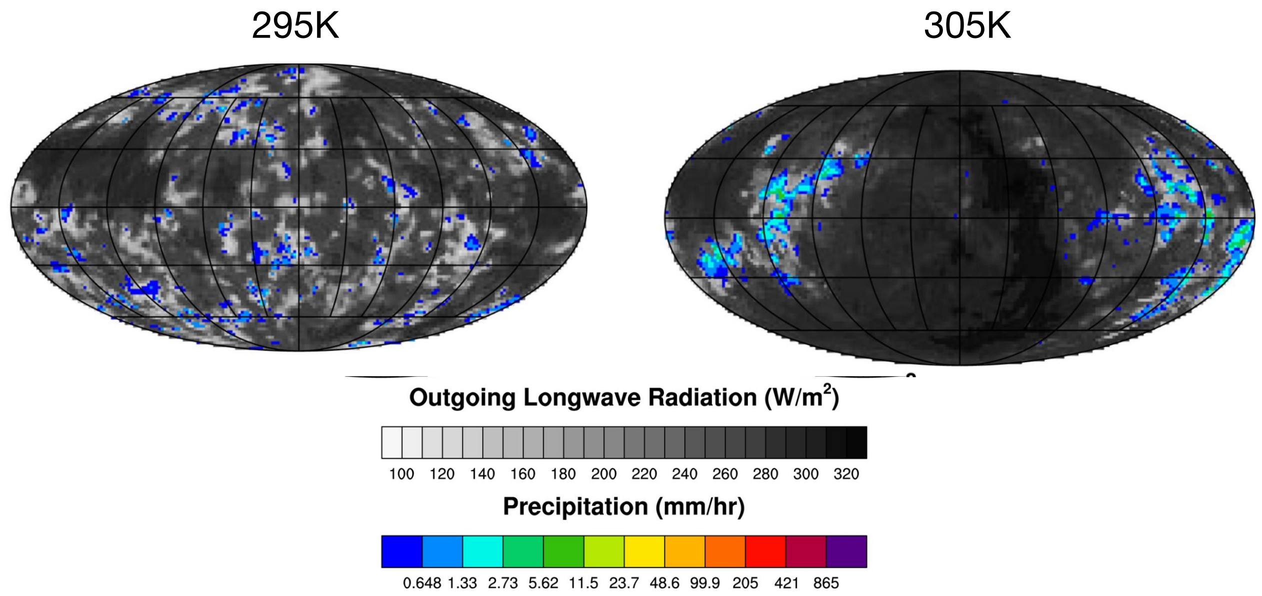


Radiative Convective Equilibrium (RCE) world:
https://www.cesm.ucar.edu/models/simple/rce

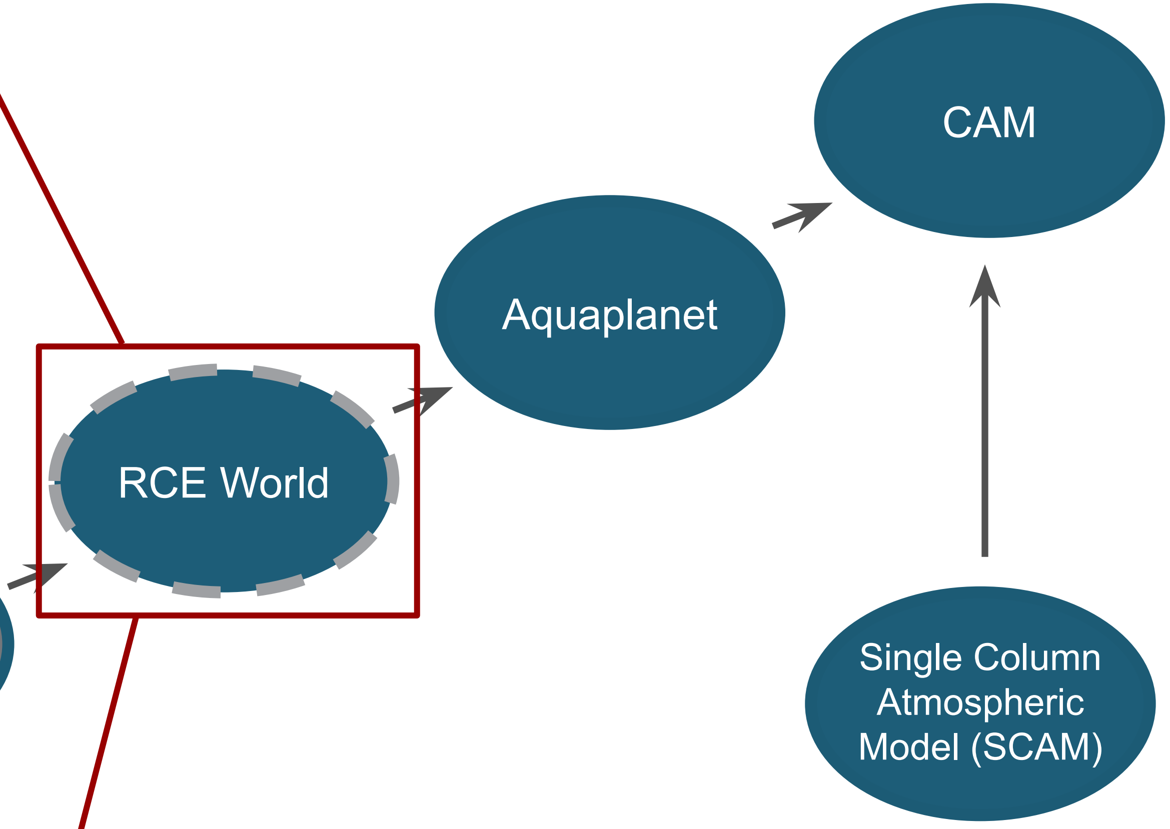
Compatible with the RCEMIP protocol.

No rotation, uniform and constant insolation
Uniform prescribed SSTs

Planetary rotation and solar zenith angle can be specified.



Reed et al (2021)



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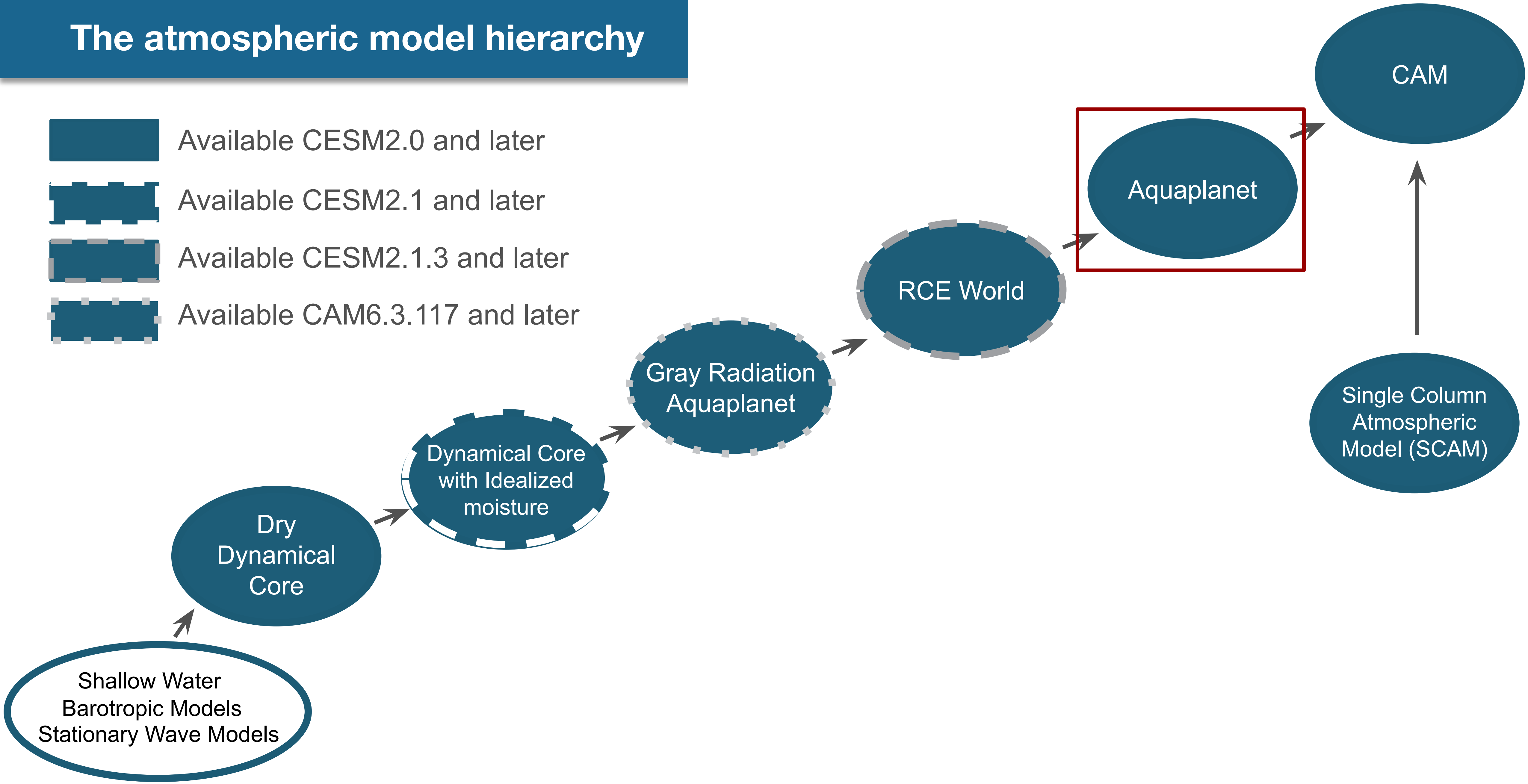


The at

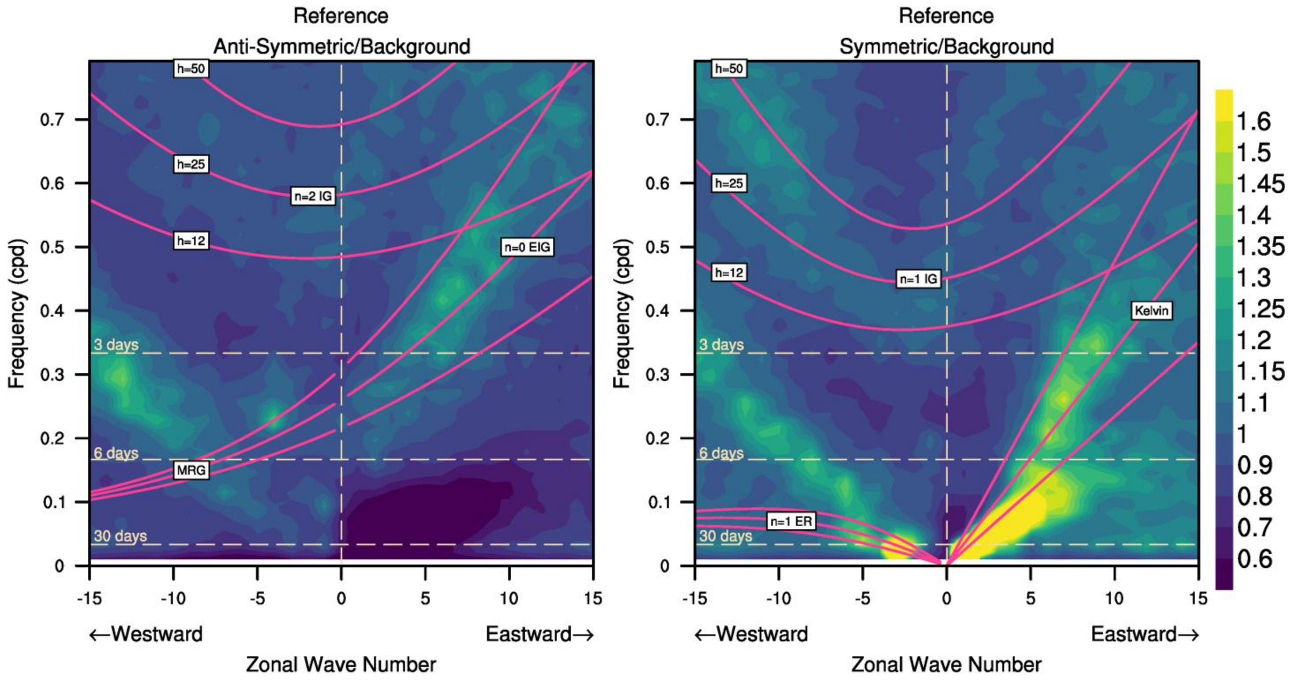
Aquaplanet: https://www.cesm.ucar.edu/models/simple/aquaplanet

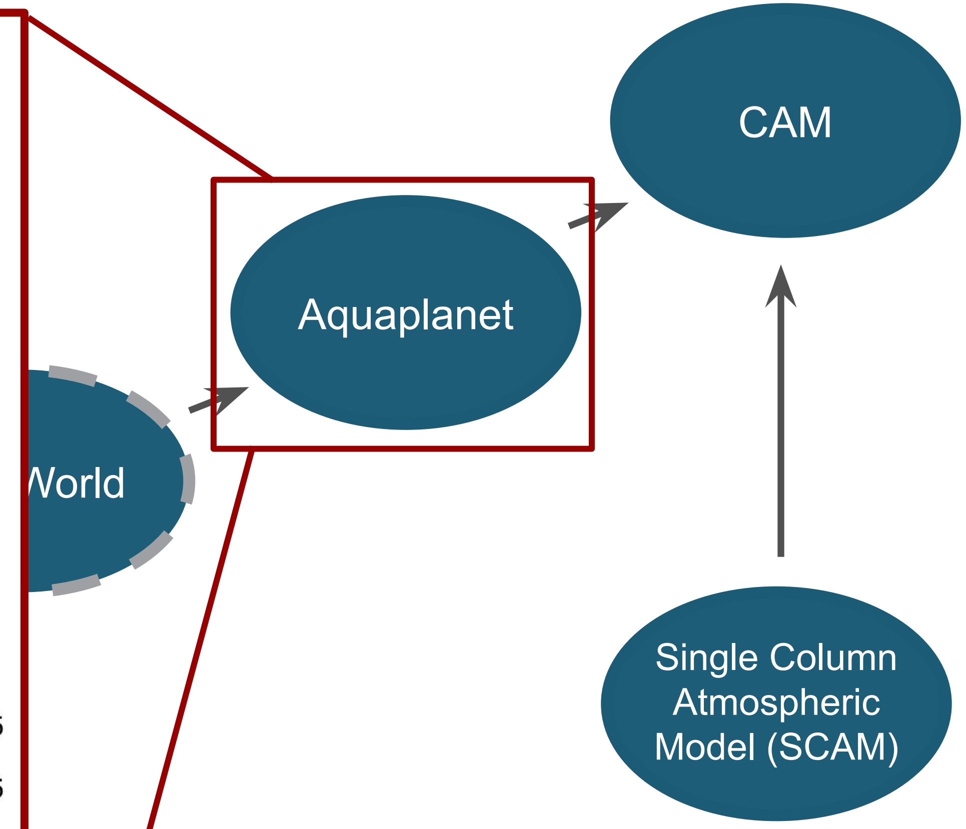
Full CAM4, CAM5 or CAM6 physics.

Water covered Earth.

Prescribed SSTs or slab ocean.

Spectra of equatorial waves in the CAM5 aquaplanet (Medeiros et al 2016)





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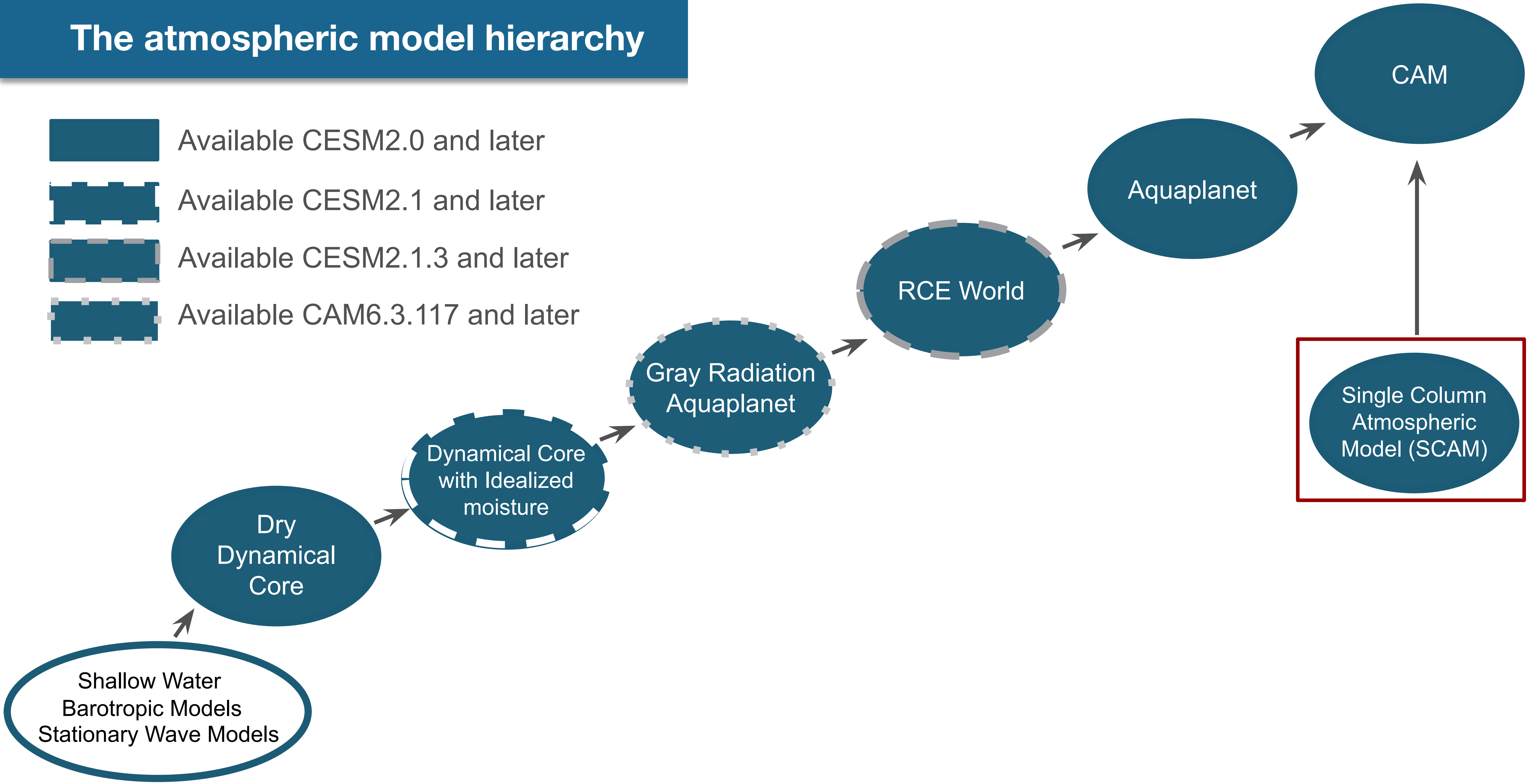

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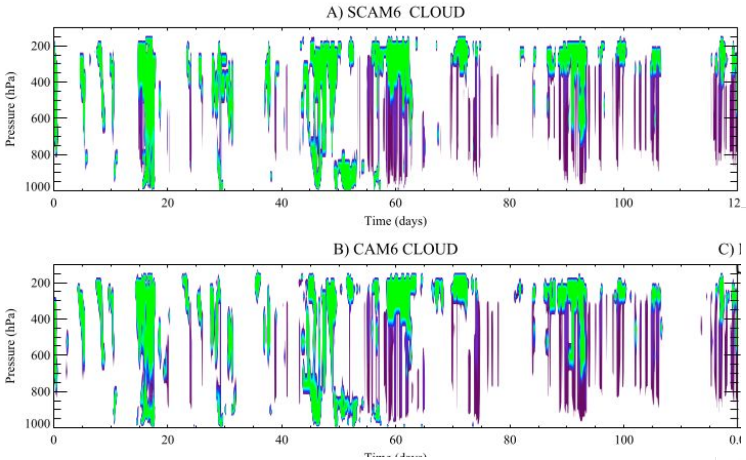
Single Column Atmospheric Model (SCAM), Gettelman et al 2019:
https://www.cesm.ucar.edu/models/simple/scam

Full CAM physics.

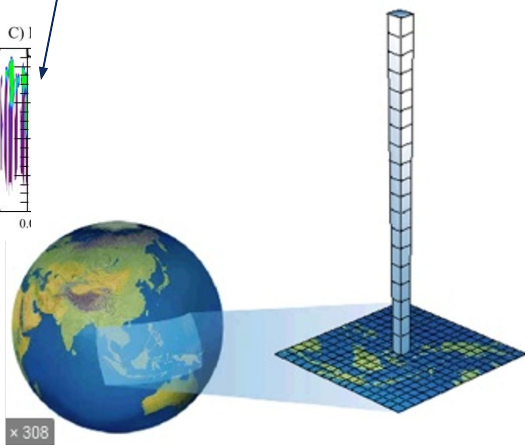
Simulation of a single column. Large scale tendencies prescribed from either observations or a simulation.

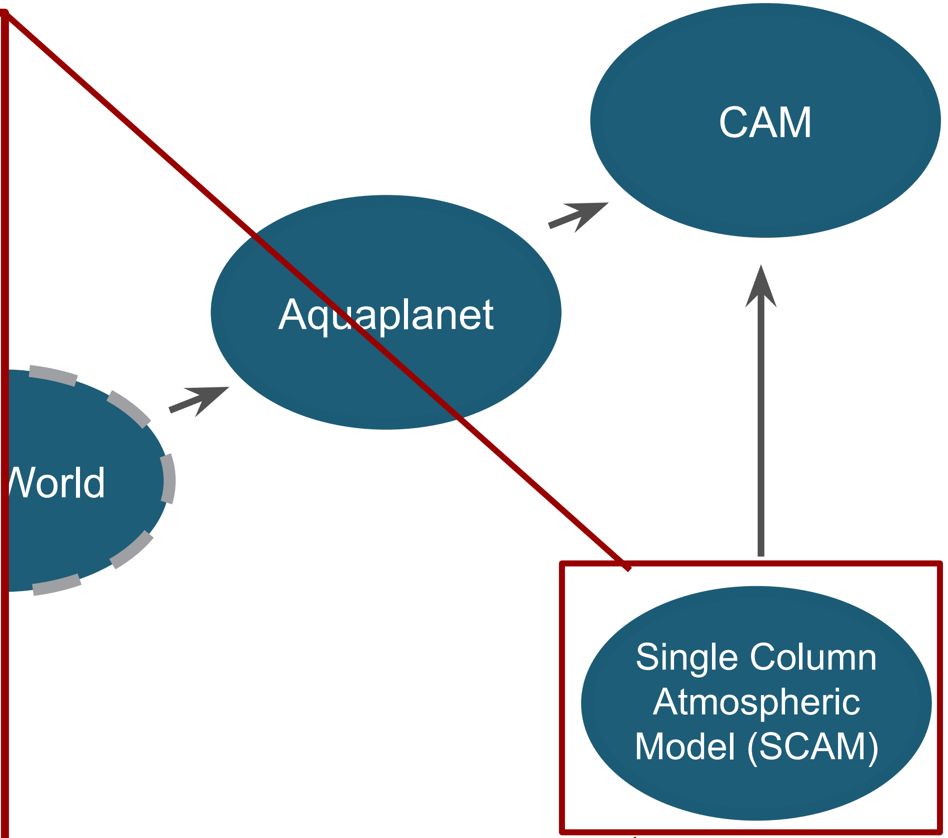
RCE and Weak Temperature Gradient parameterizations of the large scale circulation are being implemented (U. Miami, Columbia)



Cloud fraction in SCAM6 and CAM6 (Gettelman et al 2019)

Useful for parameter sensitivity studies to explore how the physical parameterizations behave under different climates and different parameter settings.





Shallow W
Barotropic
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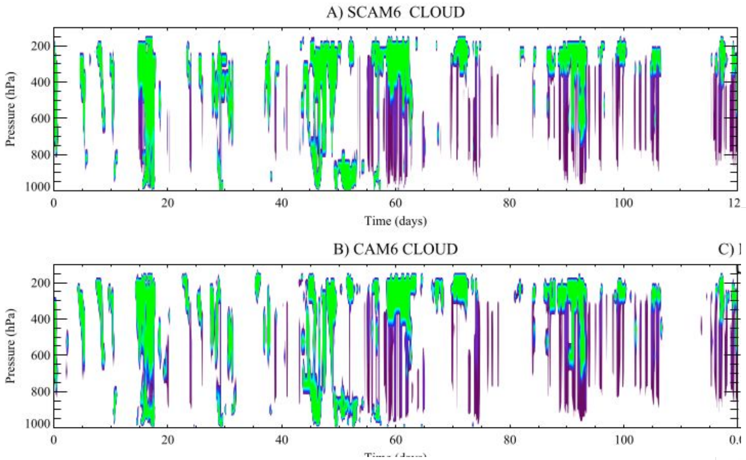

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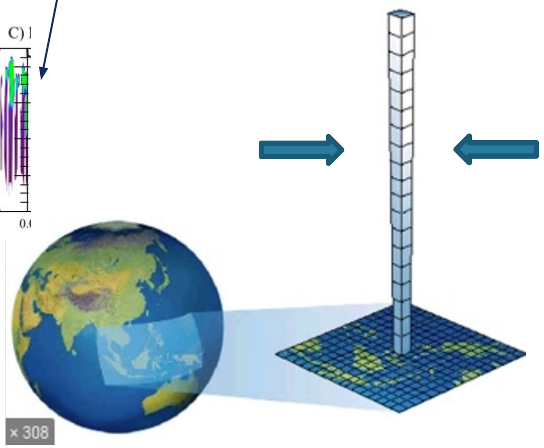

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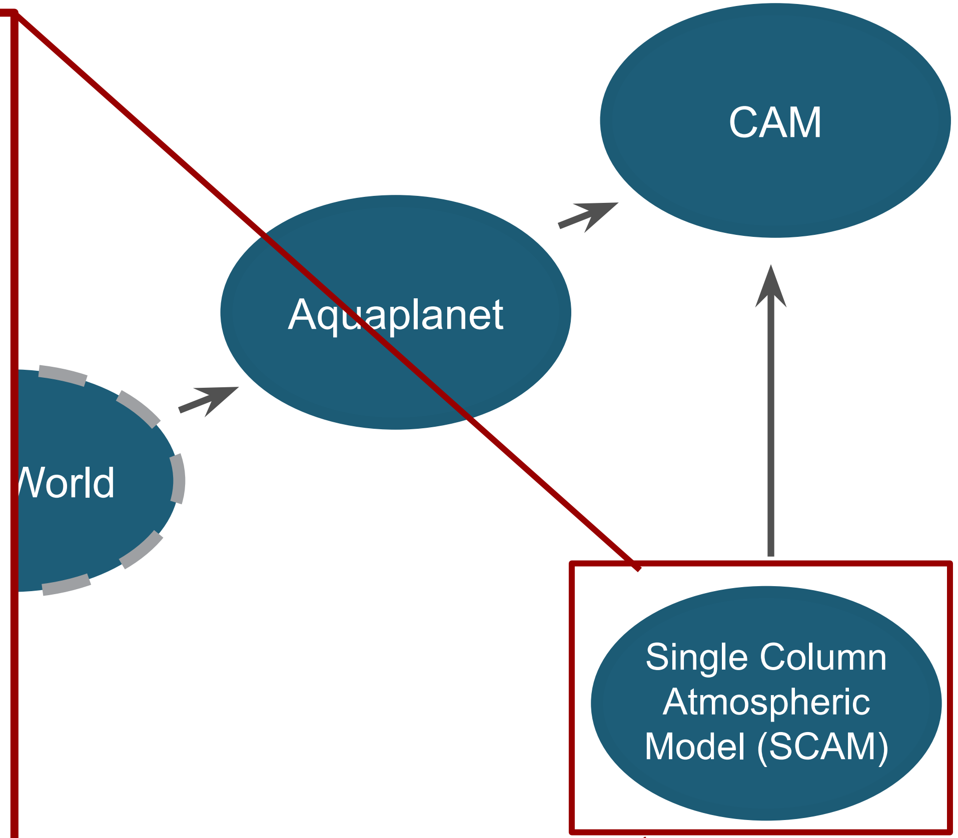


Land Simpler Models

SLIM (The Simple Land Interface Model)

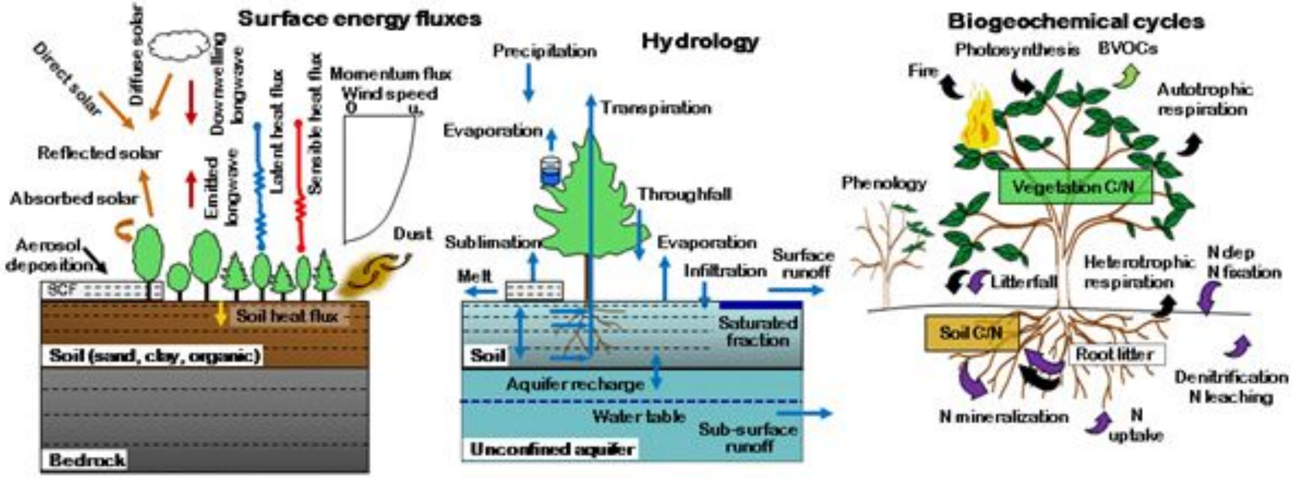
Marysa Laguë Abby Swann Gordon Bonan Erik Kluzek

Solves linearized bulk surface energy budget coupled with soil temperatures and bucket hydrology.

Prescribed: Albedo's, surface emissivity, soil conductivity and heat capacity, bucket capacity, evaporative resistance, vegetation height (aerodynamic roughness).

Allows for much more flexibility in prescribing land surface properties as opposed to letting them emerge as a result of the biophysics in CLM.

CLM5



https://www.cesm.ucar.edu/models/cesm2/land/CLM50_Tech_Note.pdf

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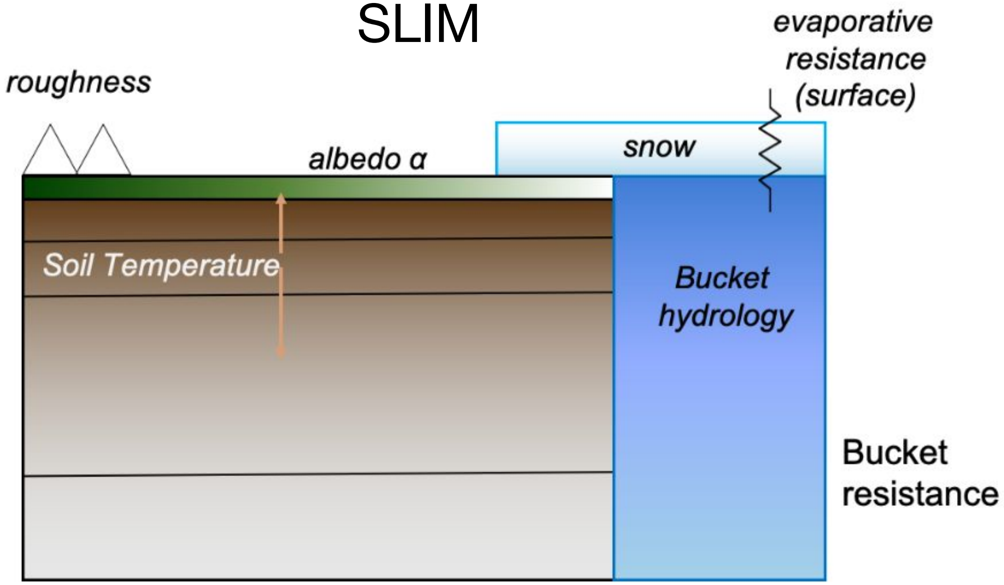


www.marysalague.com

SLIM (The Simple Land Interface Model)

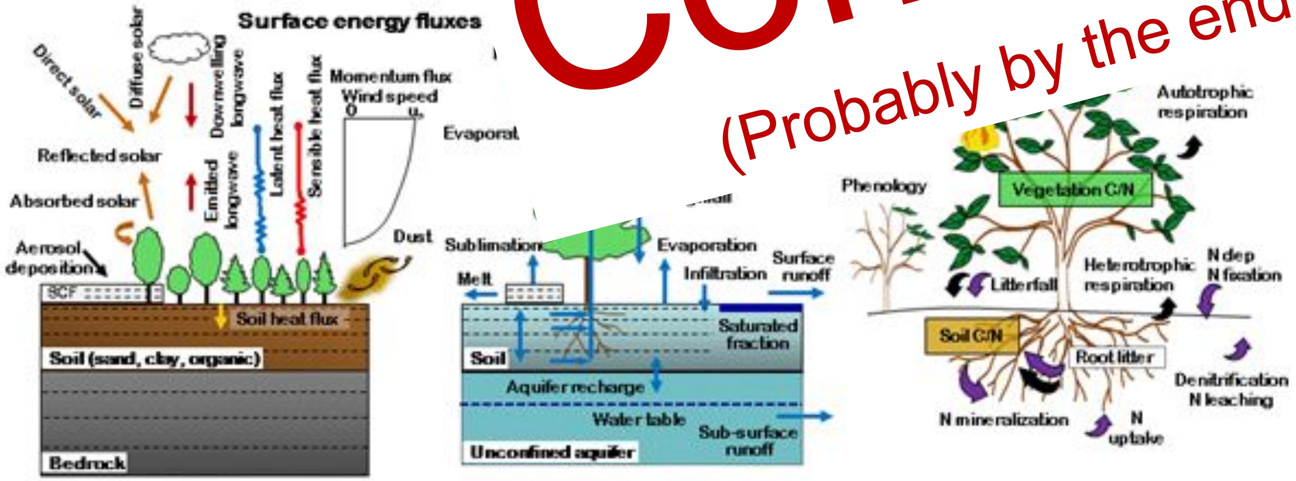
Solves linearized bulk surface energy budget coupled with soil temperatures and bucket hydrology.

Prescribed: Albedo’s, surface emissivity, soil conductivity and heat capacity, bucket capacity, evaporative resistance, vegetation height (aerodynamic roughness).

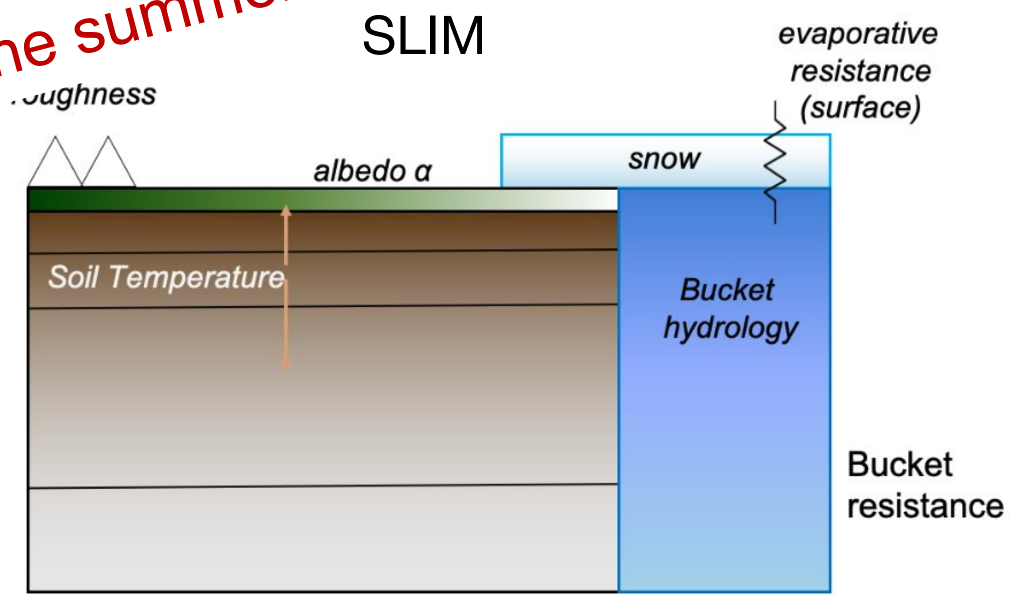
Allows for much more flexibility in prescribing land s…
opposed to letting them emerge as a resu…

Coming Soon

(Probably by the end of the summer/fall)



https://www.cesm.ucar.edu/models/cesm2/land/CLM50_Tech_Note.pdf



www.marysalague.com

Coupled Idealized Modelling

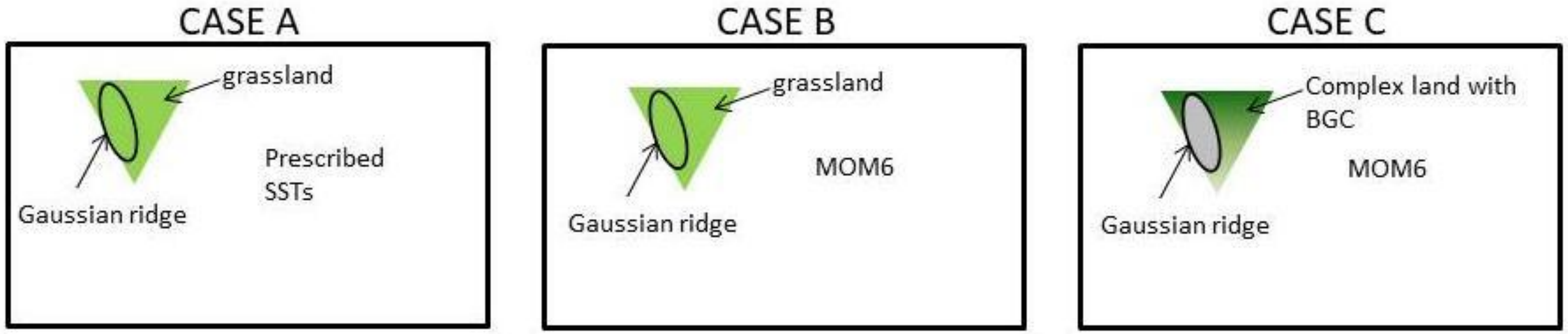
Coupled Idealized Modelling Tools – *coming soon*

NSF CSSI award 2004575

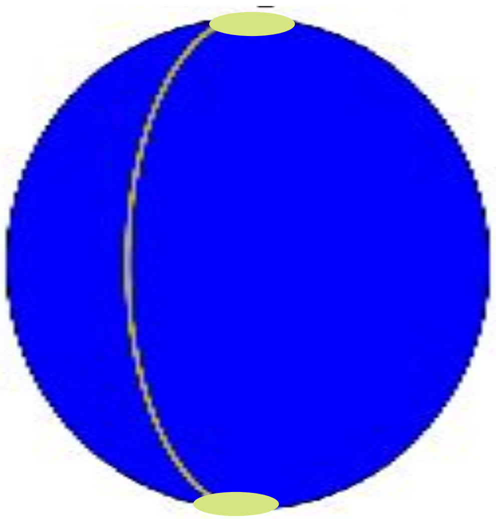
Scott Bachman | Isla Simpson | Gokhan Danabsoglu | Mariana Vertenstein | Alper Altuntas | Brian Dobbins | Sam Levis | Bill Sacks

Aim: To allow users to easily set up their own idealized coupled configurations or atmosphere-land configurations

- User defined ocean bathymetry
- User defined continental geometry
- User defined land surface properties



Ridge World

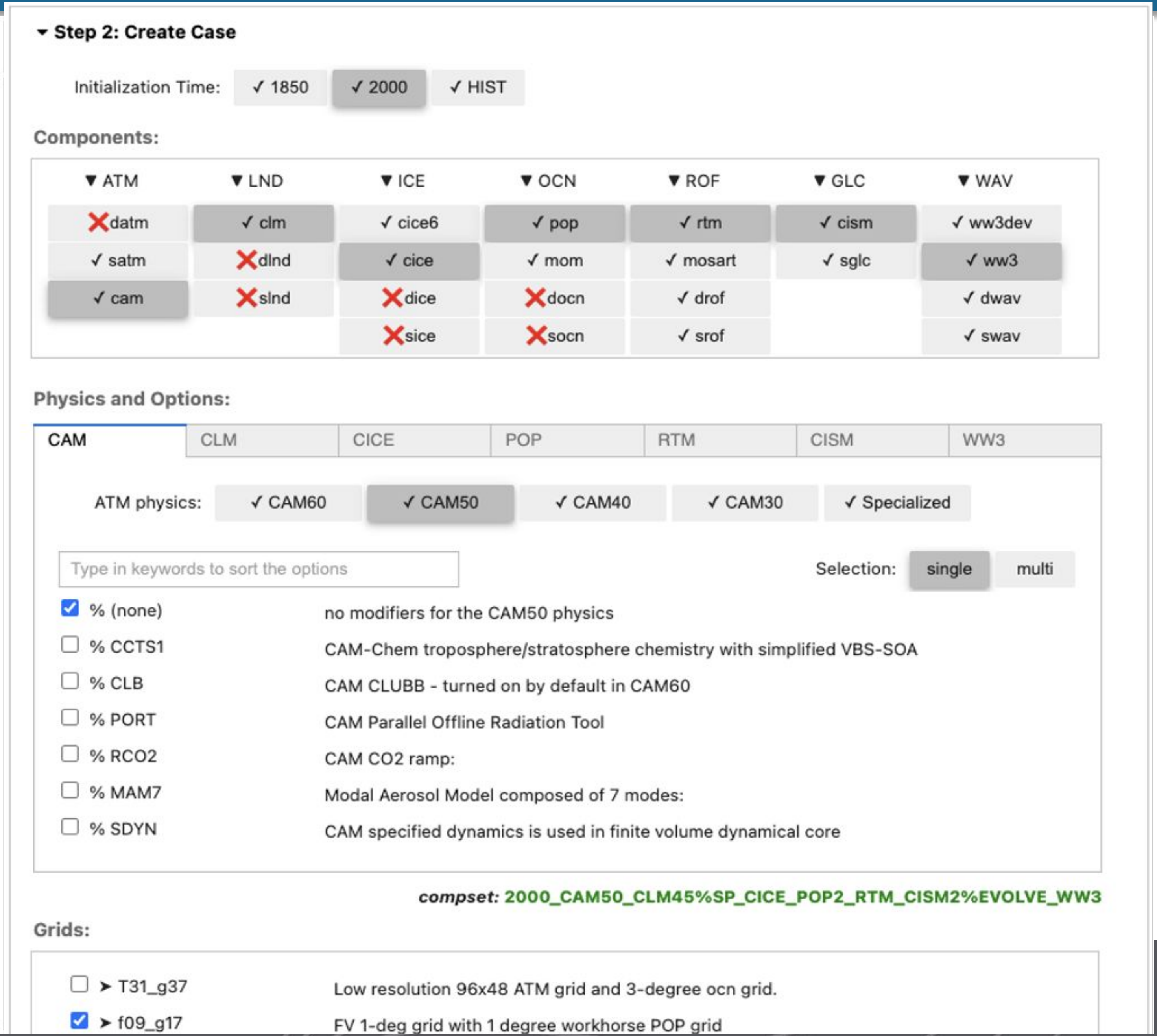


The starting point: GUI to choose your components

The GUI will allow you to choose your components and set up your component set

For idealized simulations with user defined geometries, the GUI will guide users through the different aspects that are needed for each component and to couple them together

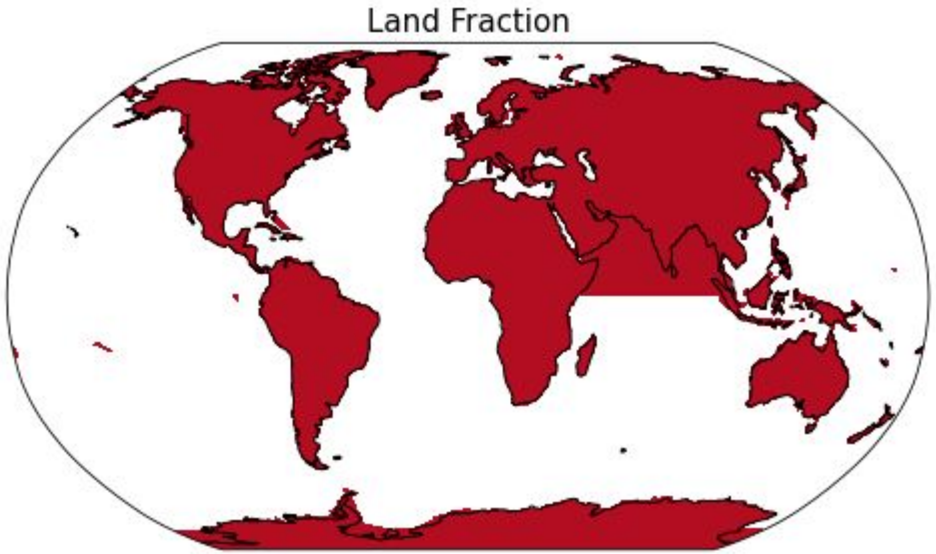
- bathymetry tool
- land surface properties tool
- mesh files for coupling



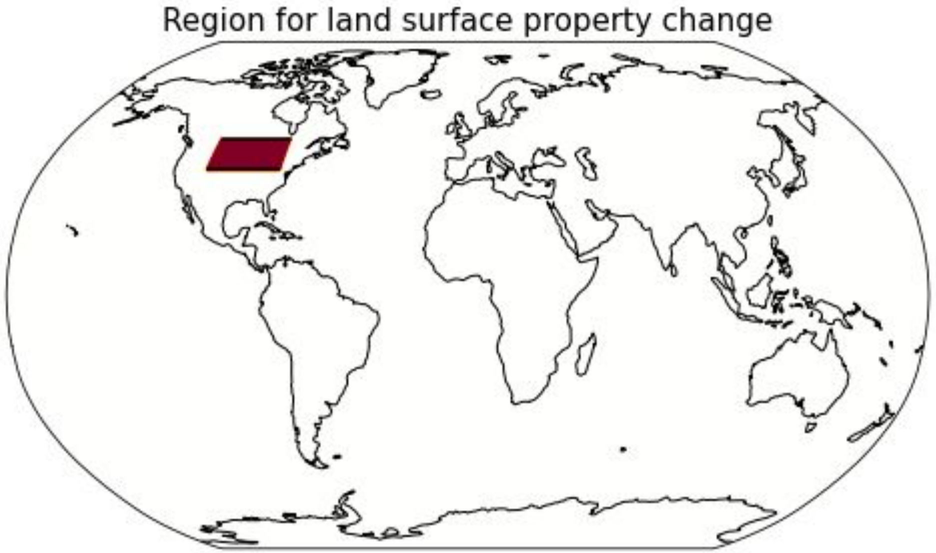
Alper Altuntas

Land surface properties tool

Tools are being developed that will allow users to easily modify both the continental geometry and land surface properties within CLM/CTSM.



Users can fill in land regions or take land regions away, as in this example where the Indian ocean has been filled in. Can specify idealized land surface properties on the new land region e.g., grassland, bare ground etc



Users can take existing land surface regions in CLM/CTSM and change the surface properties e.g., a user could take the boxed region over North America and change the plant functional types to represent forest in one simulation, grassland in another.

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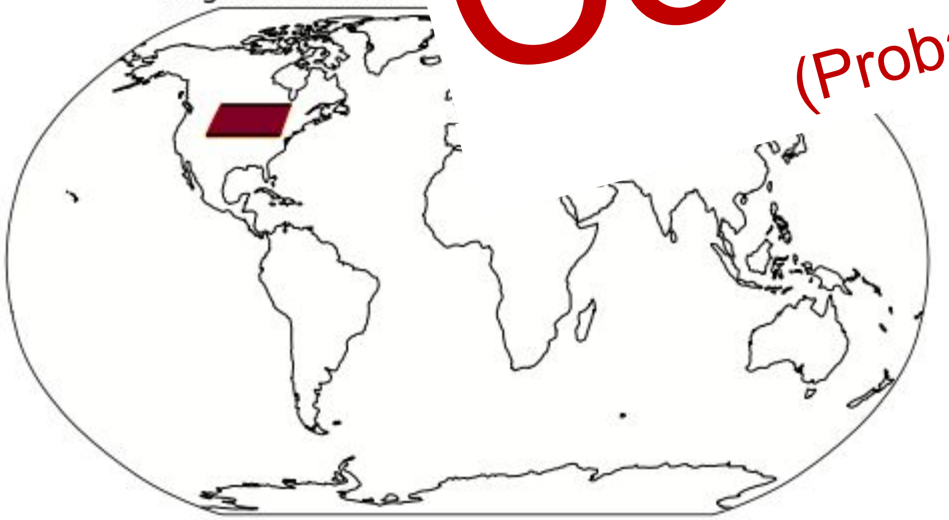
Coming Soon

(Probably within the next year)



Users can take existing land surface regions in CLM/CTSM and change the surface properties e.g., a user could take the boxed region over North America and change the plant functional types to represent forest in one simulation, grassland in another.

Conclusions

Simpler models are valuable tools to gain a process level understanding of the behavior of the real world and/or comprehensive CESM and an understanding of sensitivities within the climate system.

Many of them are cheaper to run. Some of them you can even run on your own laptop.

They are also well documented with comprehensive instructions for how to modify them.

See the simpler models website: https://www.cesm.ucar.edu/models/simple

Join the simpler models mailing list: https://mailman.cgd.ucar.edu/mailman/listinfo/cesm-simplemodels

Post query's to the bulletin board: https://bb.cgd.ucar.edu/cesm/forums/simpler-models.161/

My email address: islas@ucar.edu

Extra Slides

The Pencil Model – *coming soon*

Single column ocean model at each grid point.

No large scale ocean dynamics (prescribed tendencies of temperature and salinity to maintain climatology close to the coupled model).

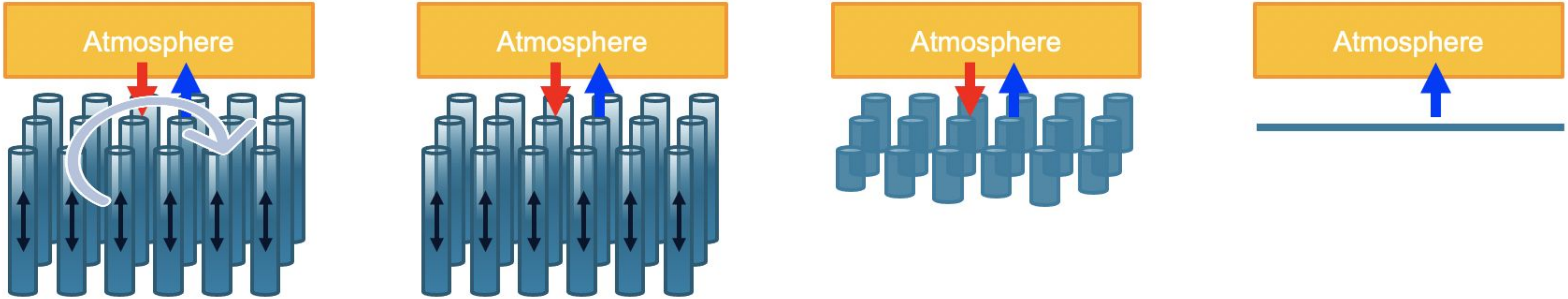
Representation of mixed layer physics, prognostic mixed layer depth etc.

Methodology currently being refined and long simulations about to begin.

Young-Oh Kwon   Ivan Lima   Gokhan Danabasoglu

+ others…

Choices for the ocean model in CESM



Full 3-D Ocean   Pencil Ocean   Slab Ocean   Data Ocean