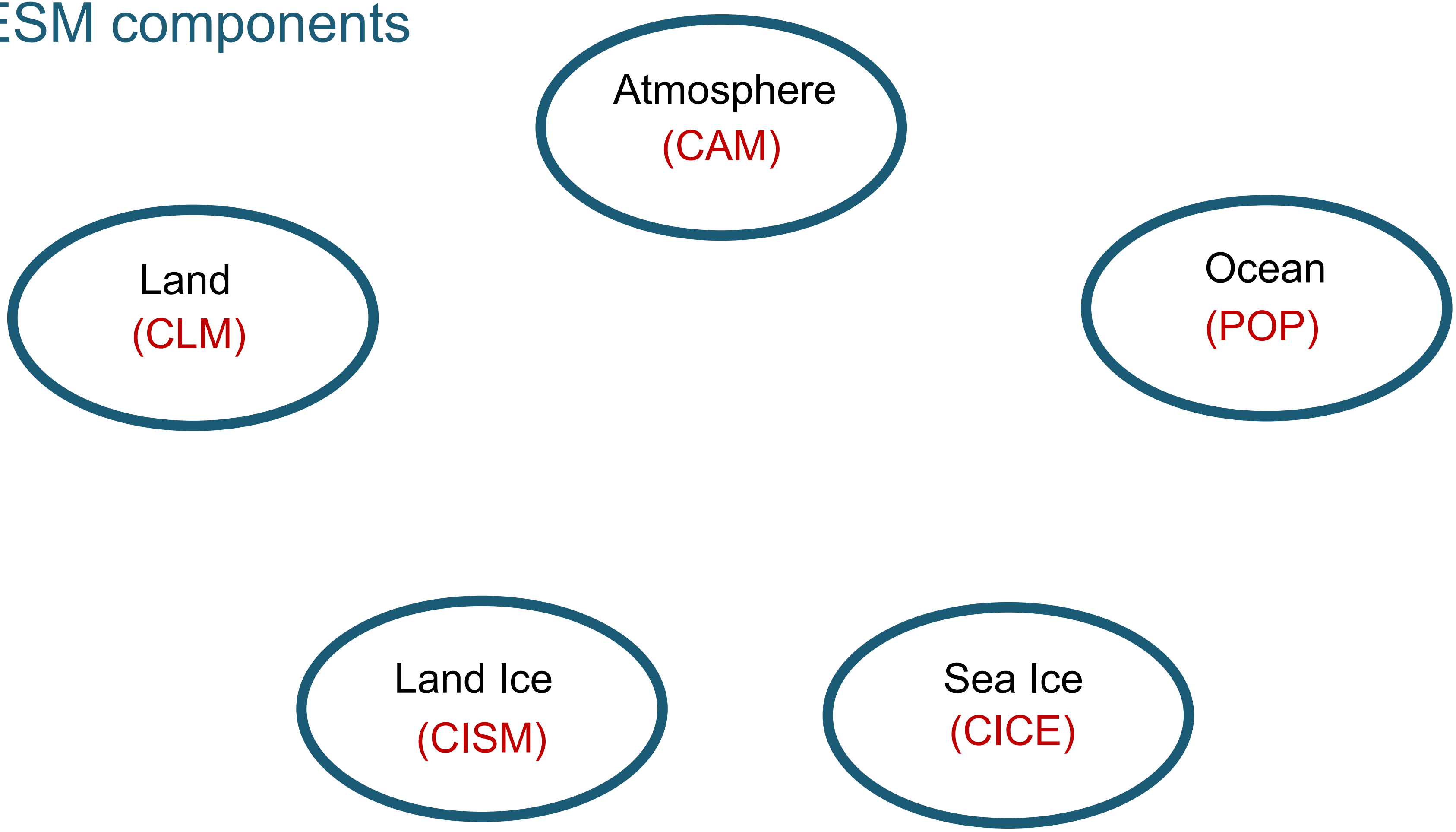
JULY 10, 2026

Idealized modeling within the CESM framework

Isla Simpson

Many contributors (in alphabetical order): Alper Altuntas, Scott Bachman, Jim Benedict, Patrick Callaghan, Cheryl Craig, Gokhan Danabasoglu, Brian 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, Mariana Vertenstein, Colin Zarzycki

CESM components



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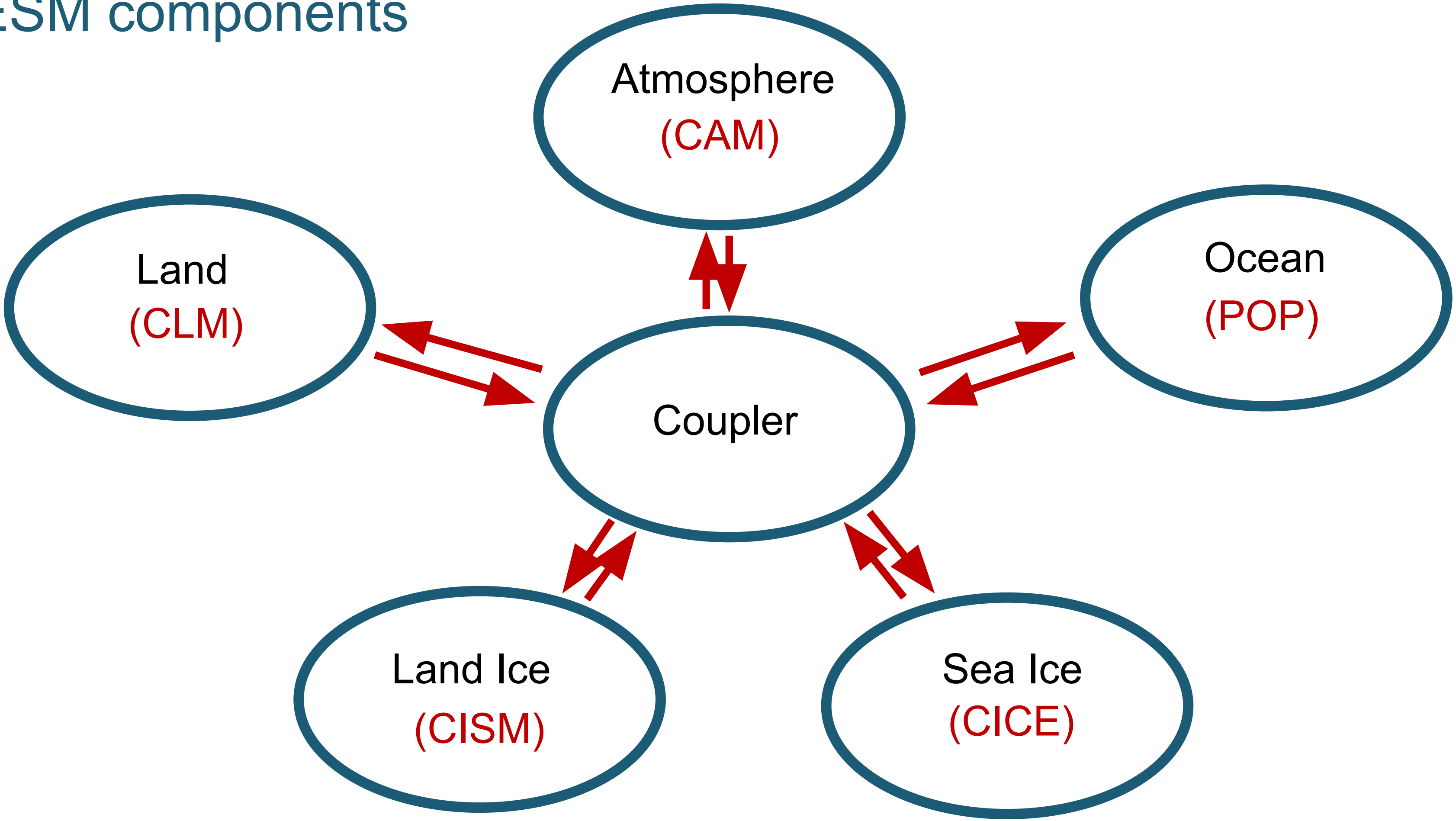

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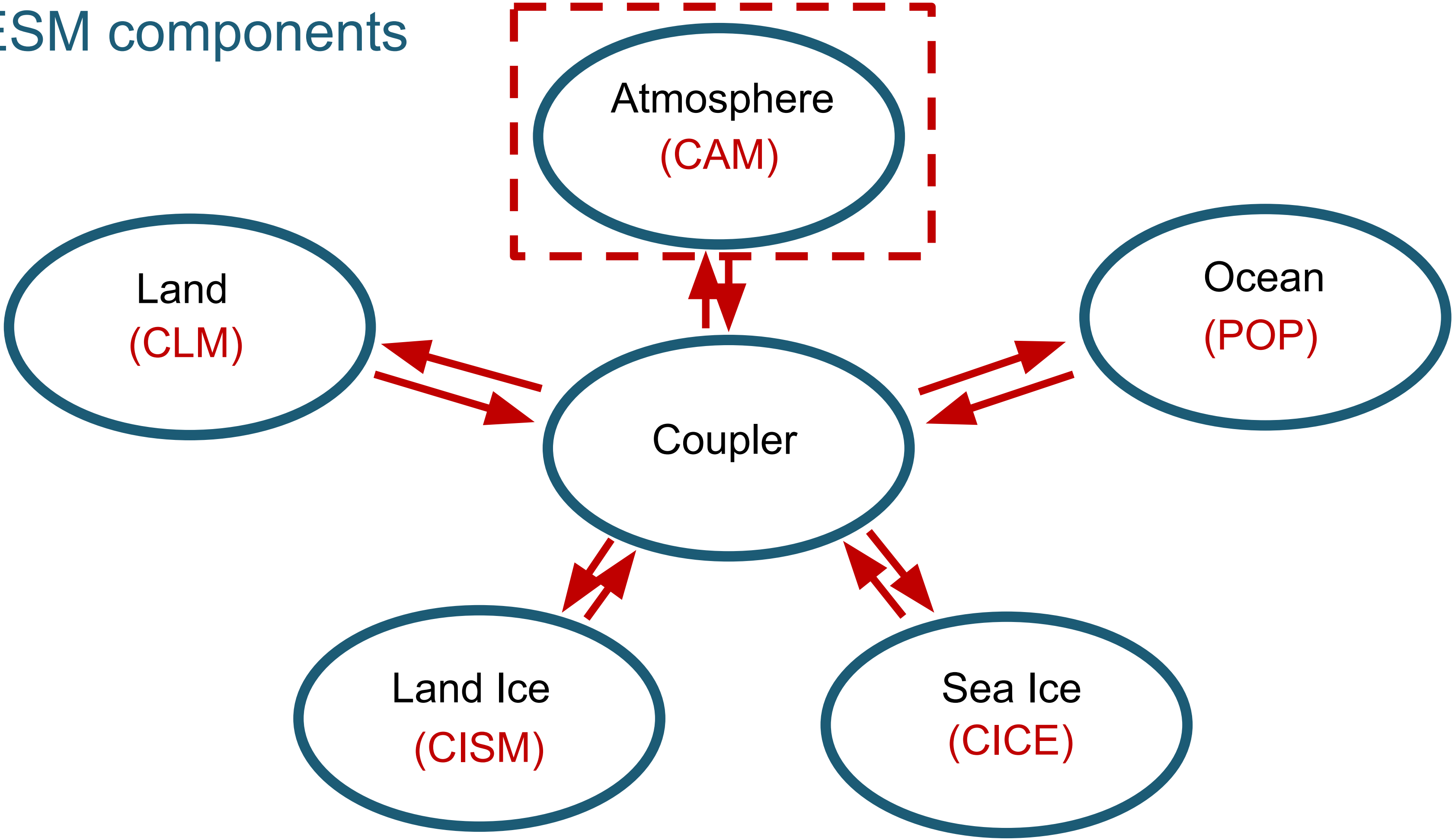

CAM

Dynamics

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

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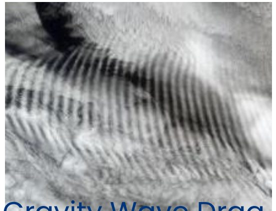
Physical Parameterizations

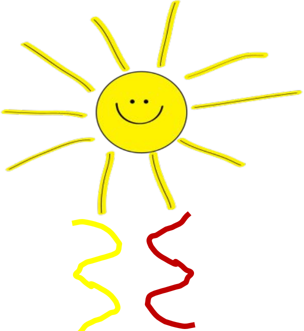


Gravity Wave Drag

Convection

Moist Processes

Cloud Physics

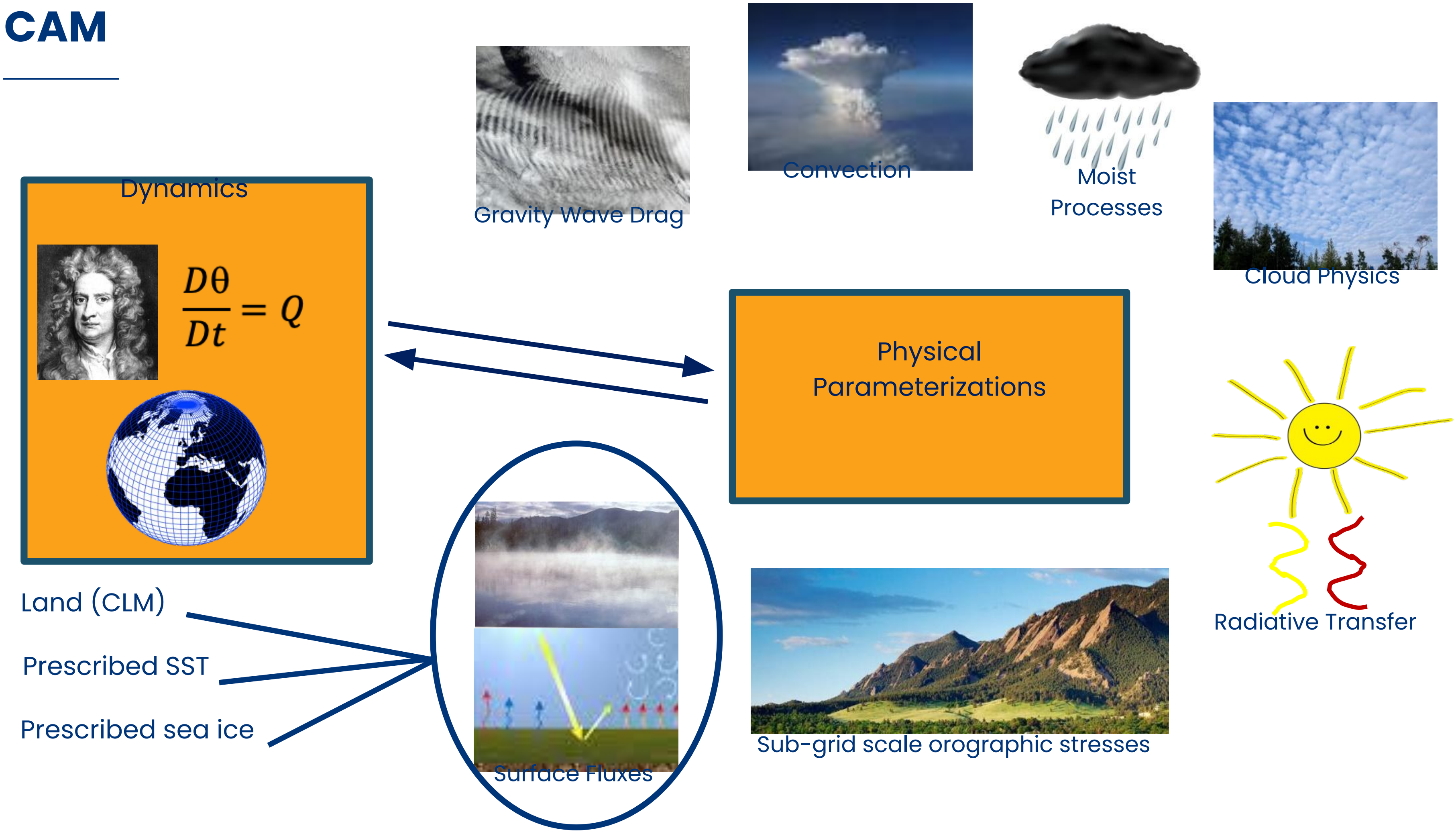


Radiative Transfer

Surface Fluxes

Sub-grid scale orographic stresses

CAM



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Land (CLM)
Prescribed SST
Prescribed sea ice
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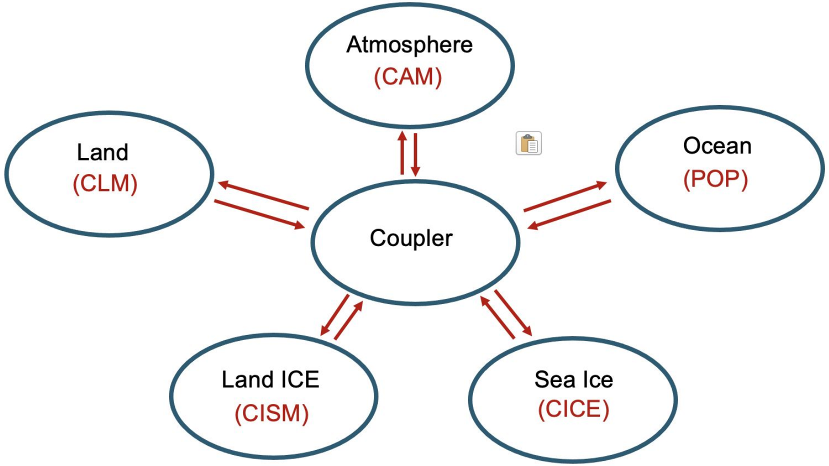
Sub-grid scale orographic stresses


Atmosphere
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Land ICE
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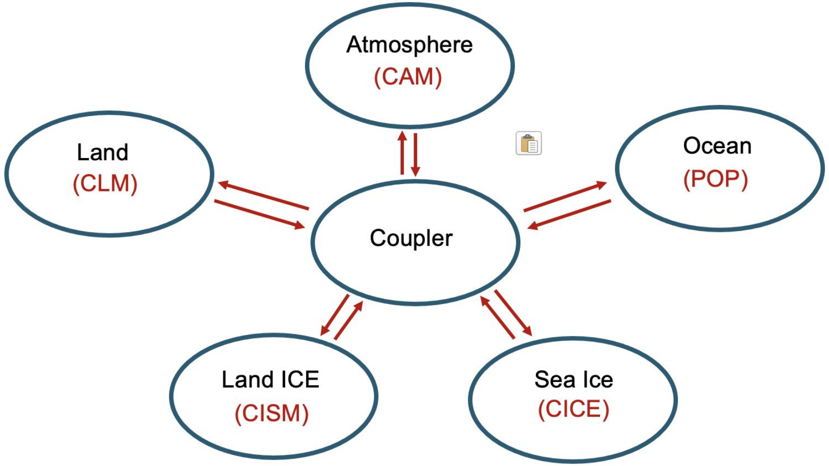
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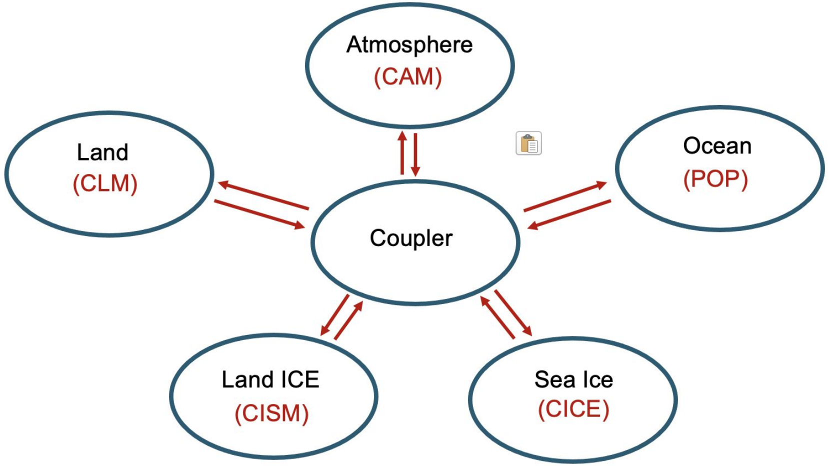
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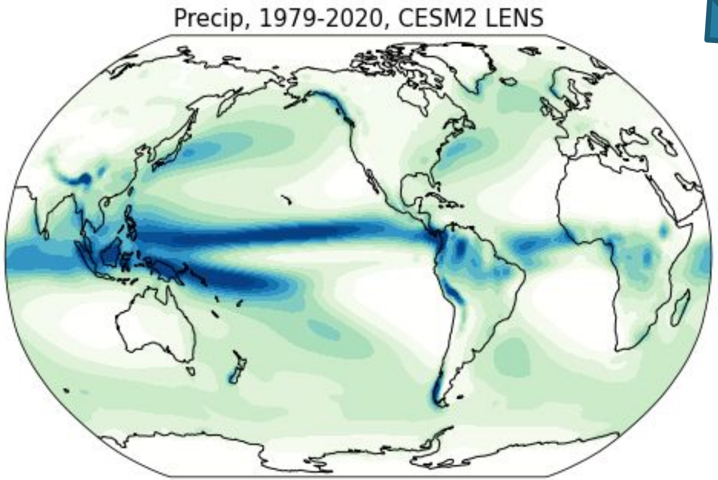
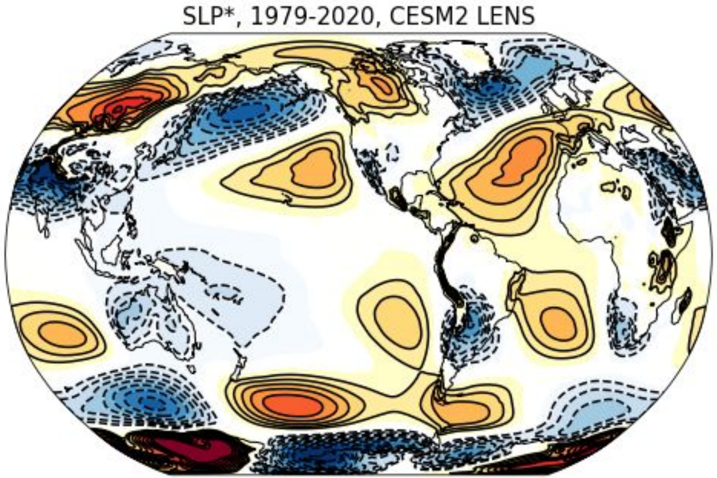
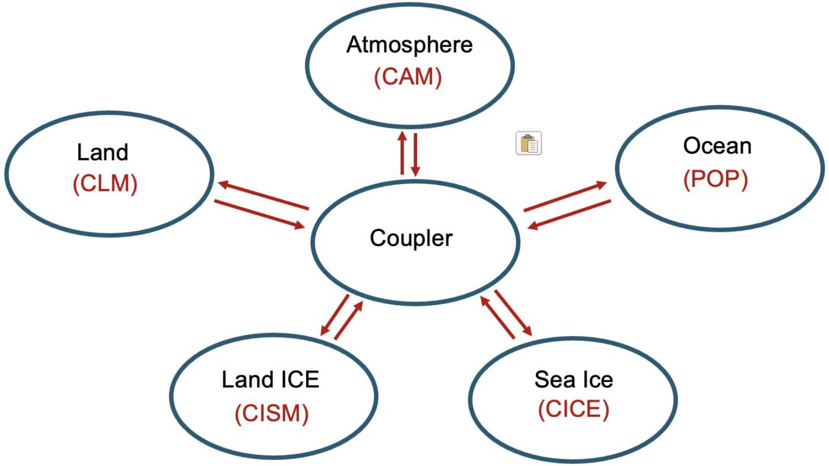

Precip, 1979-2020, CESM2 LENS


SLP*, 1979-2020, CESM2 LENS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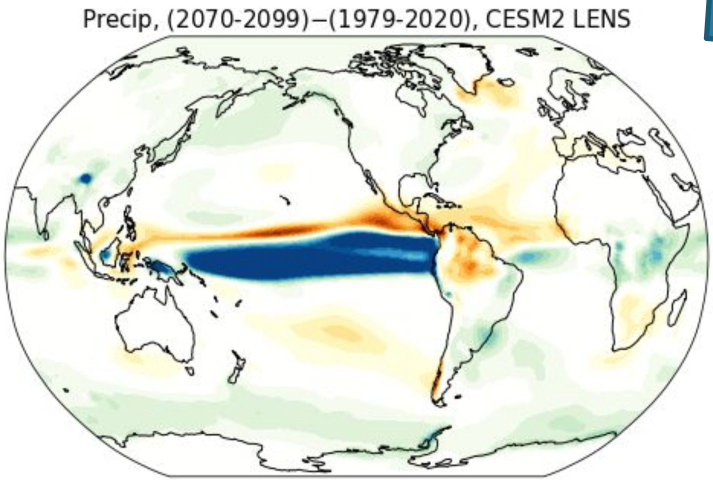
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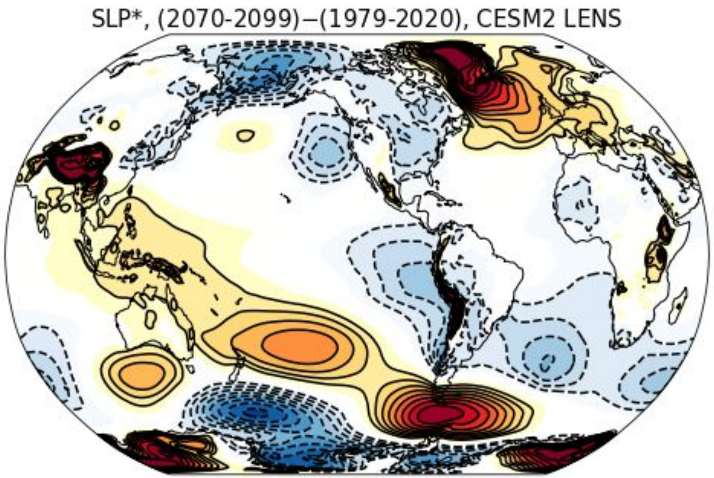
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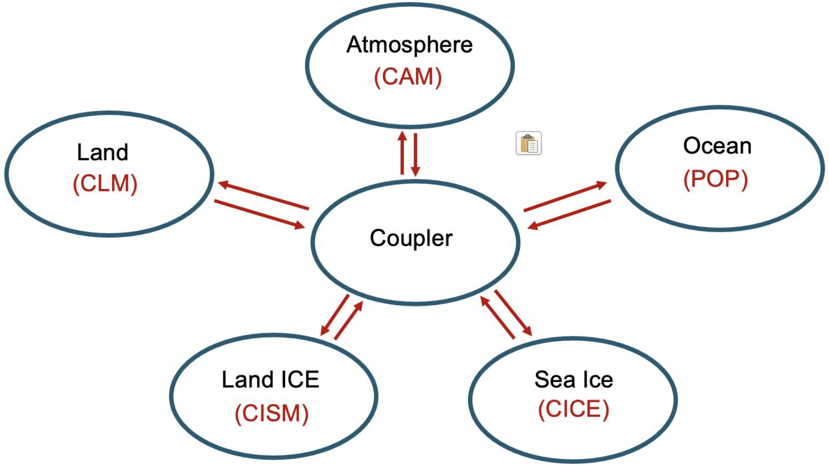
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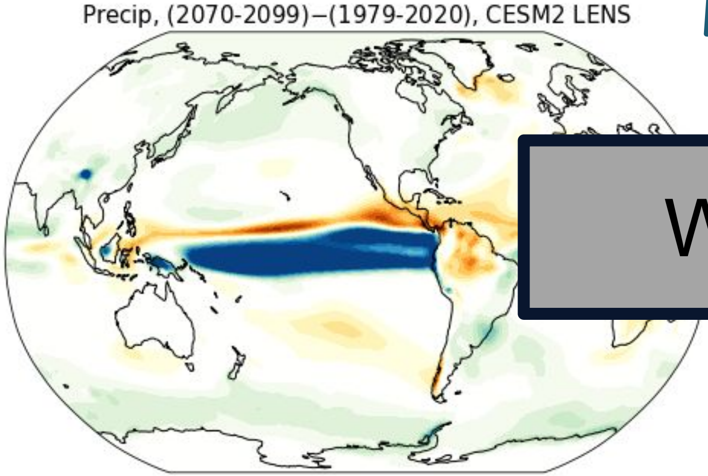
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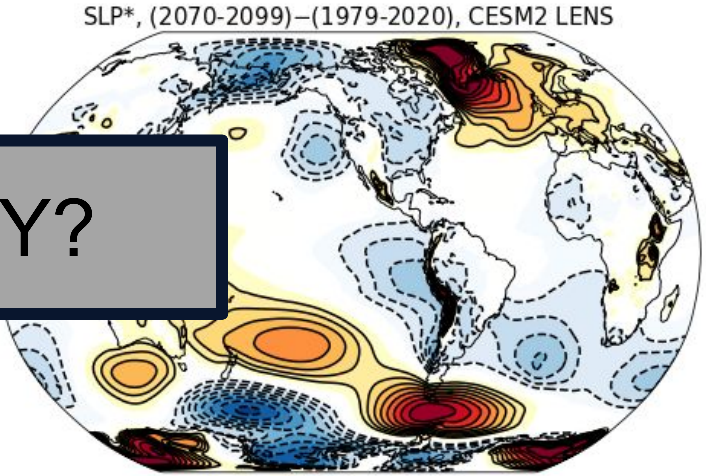
WHY?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Problems

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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 response, making it difficult to establish causal relationships.
- To obtain the solution we had to use a large supercomputer speaks to the complexity involved

How can we pull it all apart and understand it?

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- Detailed diagnosis of model output

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We now have a lot of idealized modeling capabilities within CESM

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

What are idealized/simpler models?

They are stripped down versions of CESM that only contain certain components and/or idealized representation of certain components

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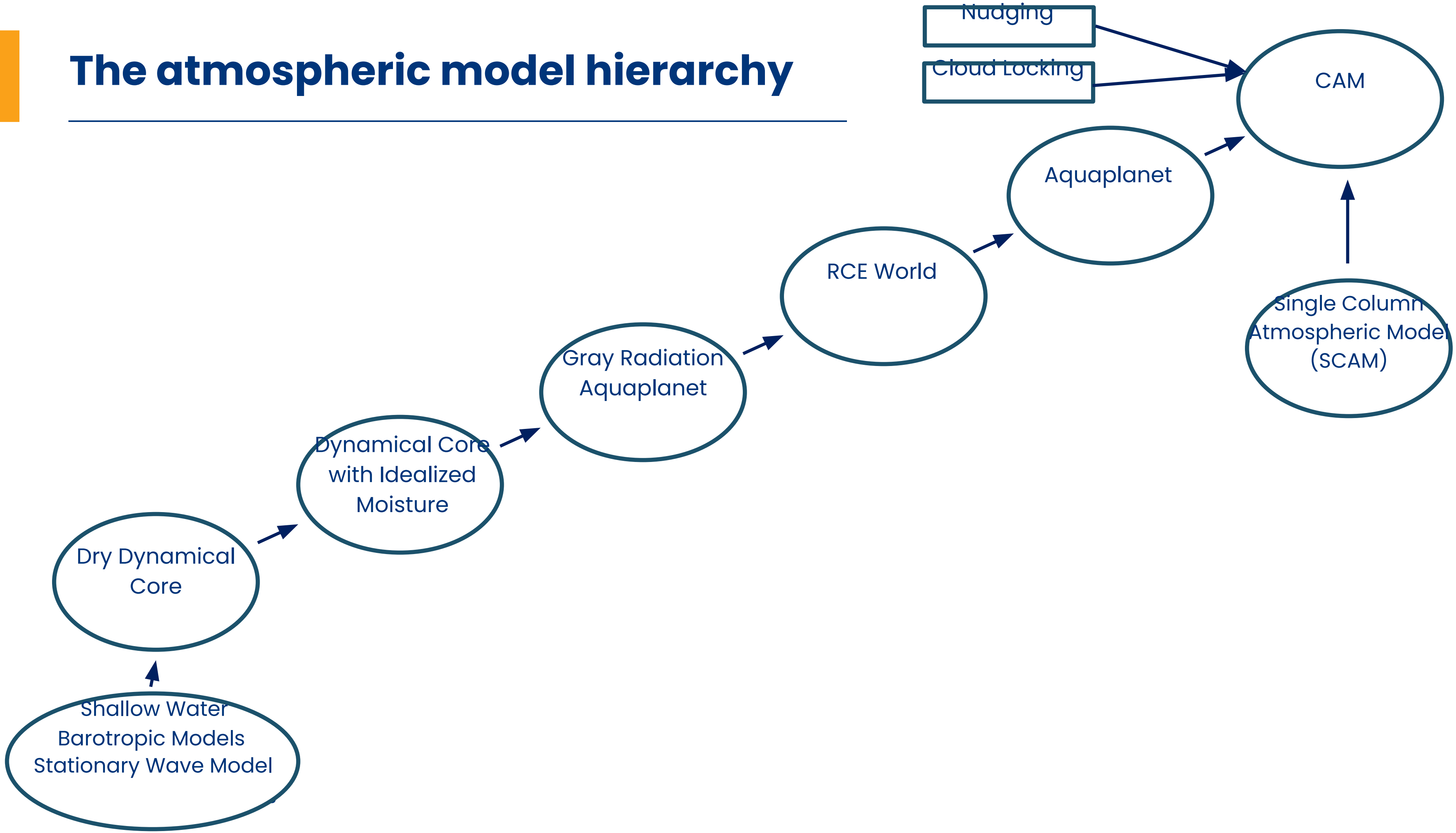
Always keep your eye on the real world/full CESM. Use the hierarchy.

Atmospheric Simpler Models

The atmospheric model hierarchy



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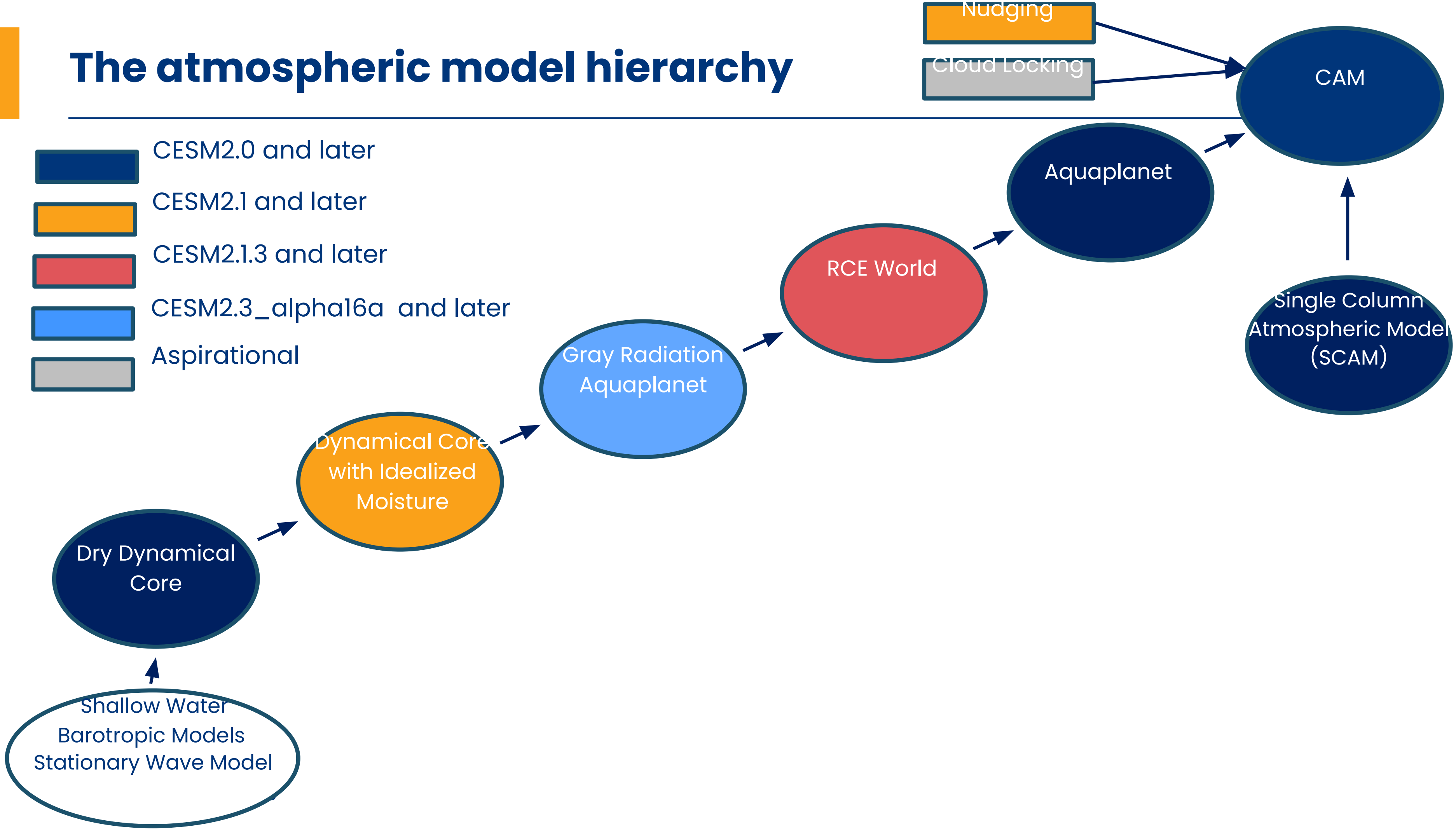

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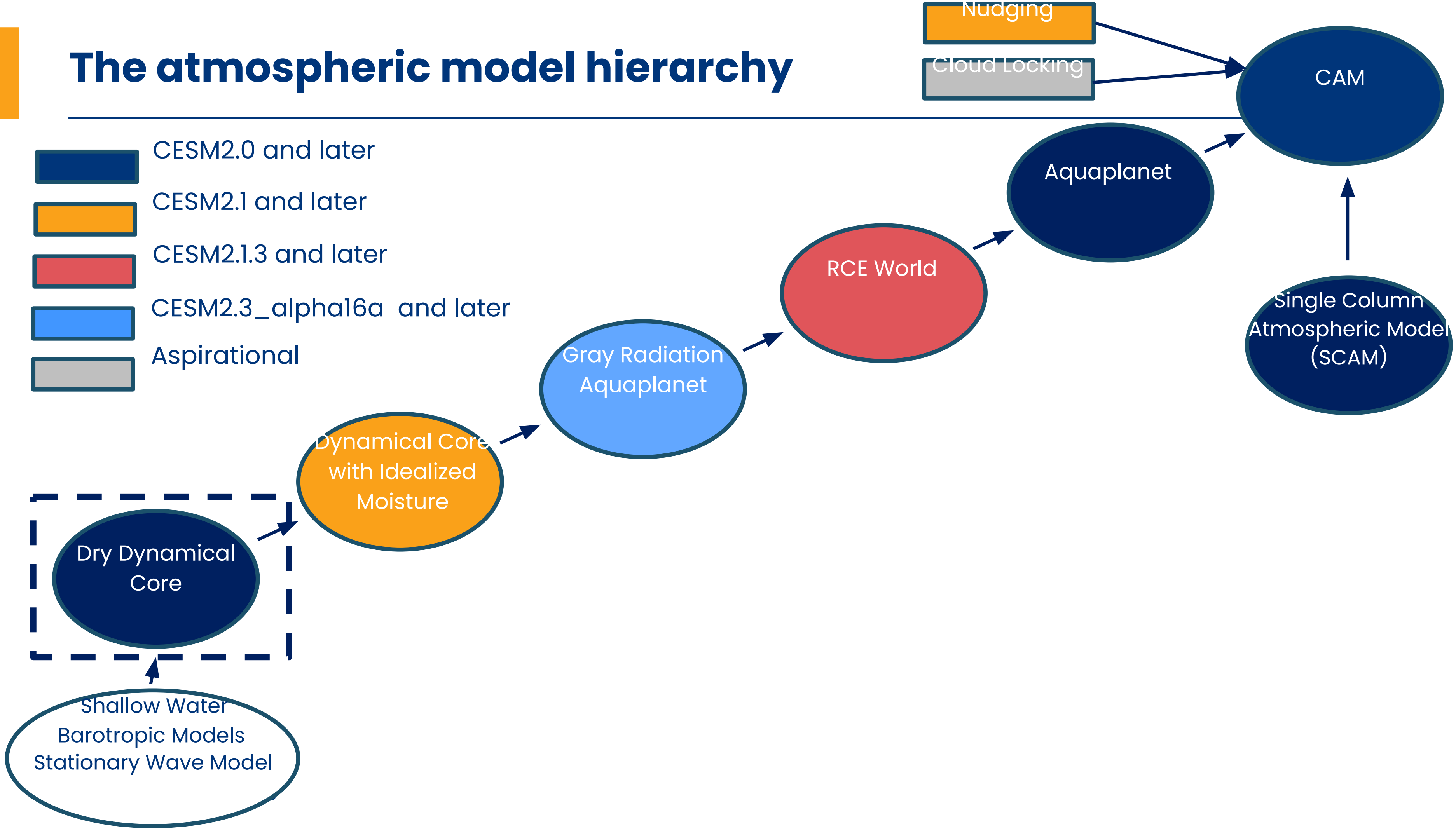

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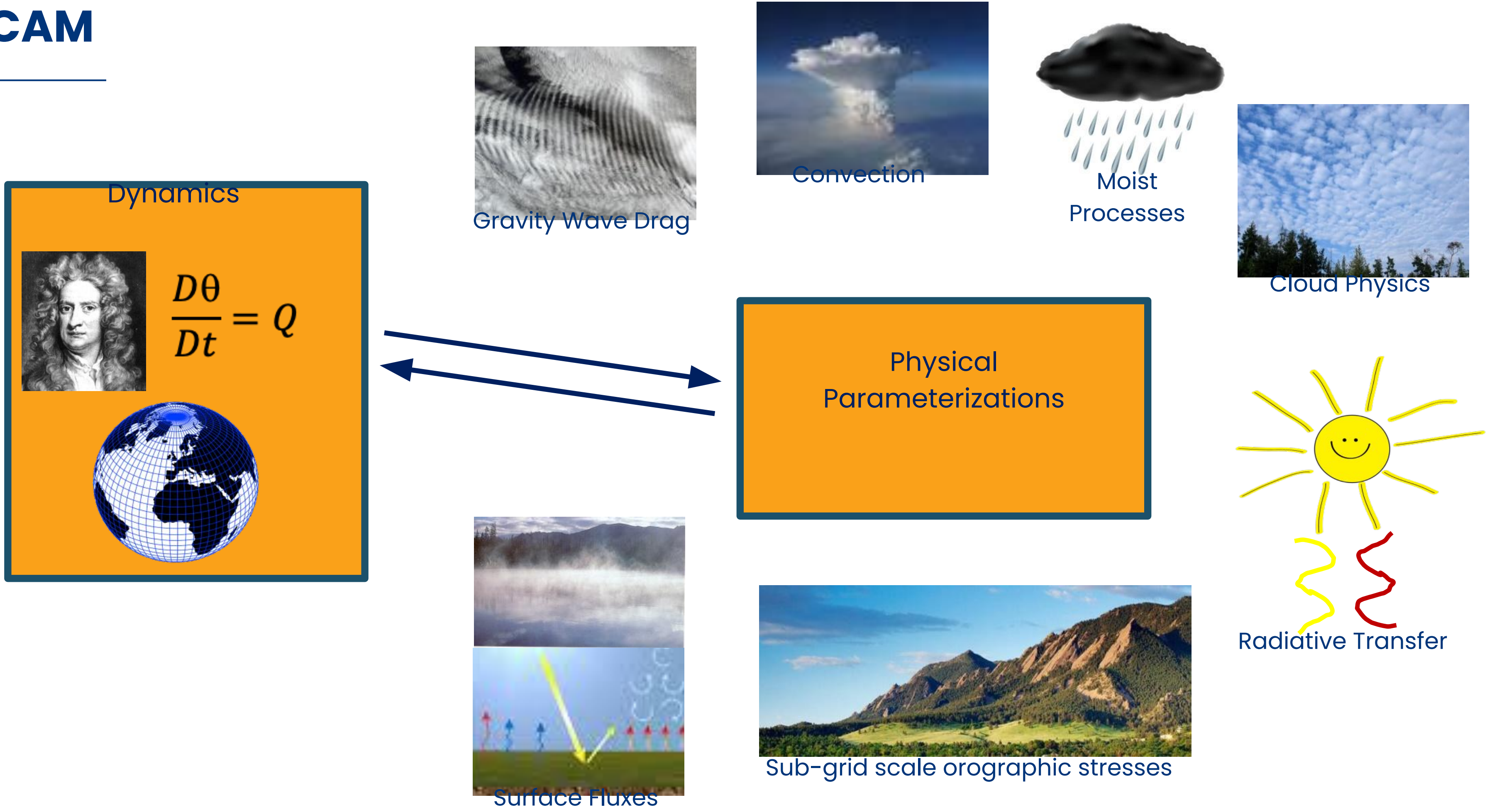
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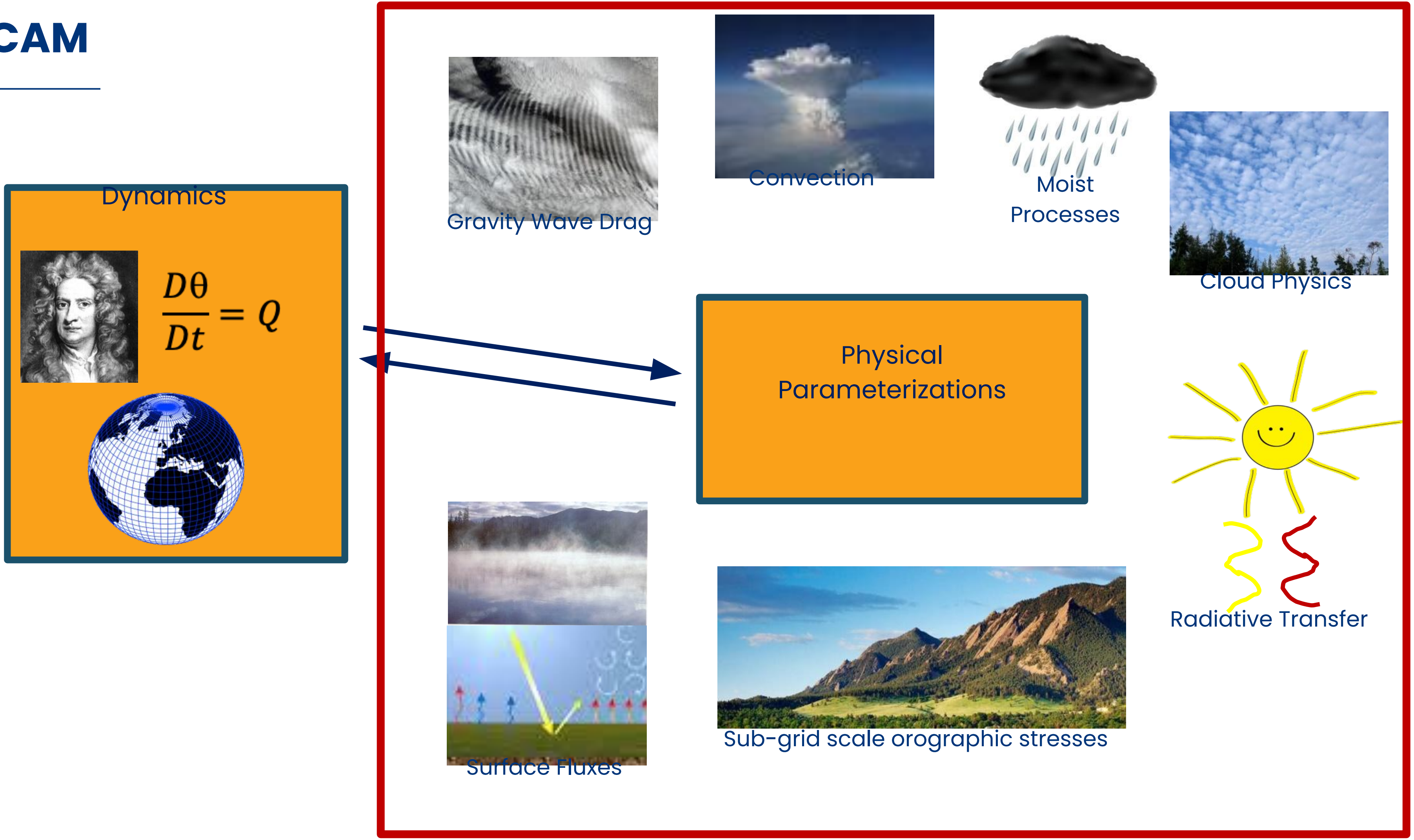
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Dry Dynamical Core

Dynamics

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

Newtonian relaxation of the temperature field towards a specified equilibrium profile

$$\frac{\partial T}{\ } = \dots - \frac{T - T_{eq}}{\ }$$

Linear drag on winds at the lowest levels

$$\frac{\partial \vec{v}}{\ } = \dots - k\vec{v}$$

The atmospher

CESM2.0 and later

CESM2.1 and later

CESM2.1.3 and later

CESM2.3_alpha16a

Aspirational

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Dry Dynamical Core

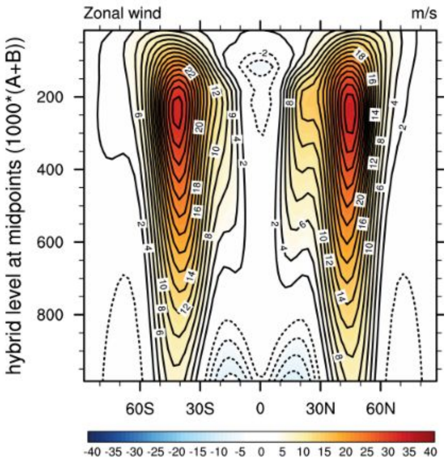
Shallow Water
Barotropic Models
Stationary Wave Model

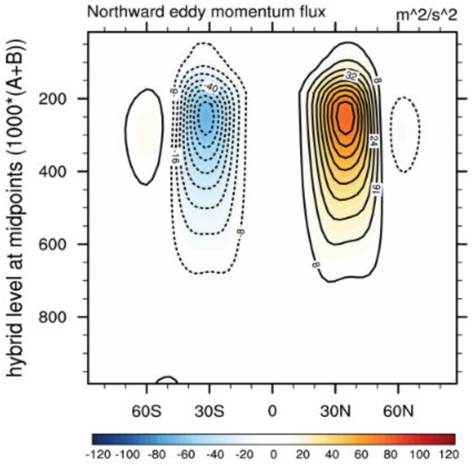
Dry dynamical core:
https://www.cesm.ucar.edu/models/simple/dry-dynamical-core

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 (Held and Suarez 1994)

Currently runs with all dynamical cores available within CESM: Finite Volume, Spectral Element, MPAS, FV3

Good for dry dynamics. Can easily perturb the temperature.





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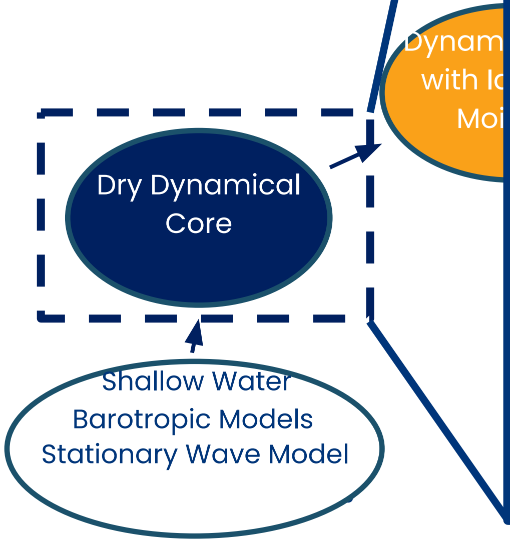

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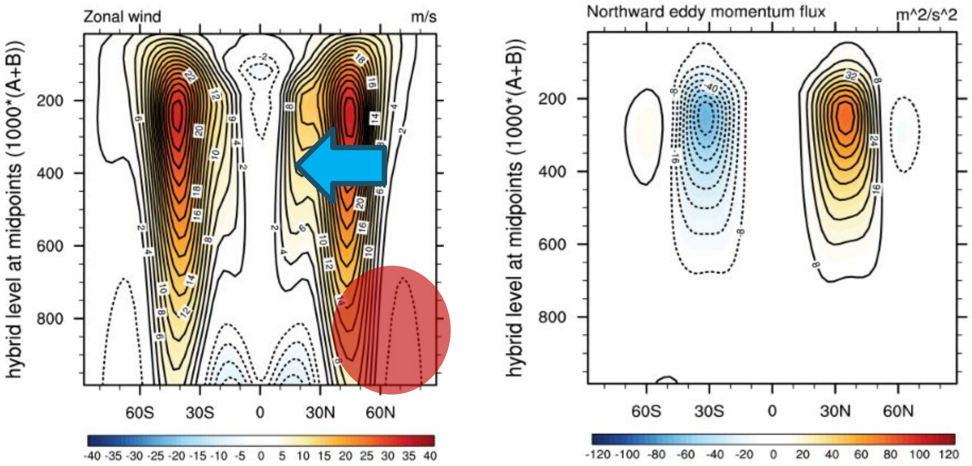
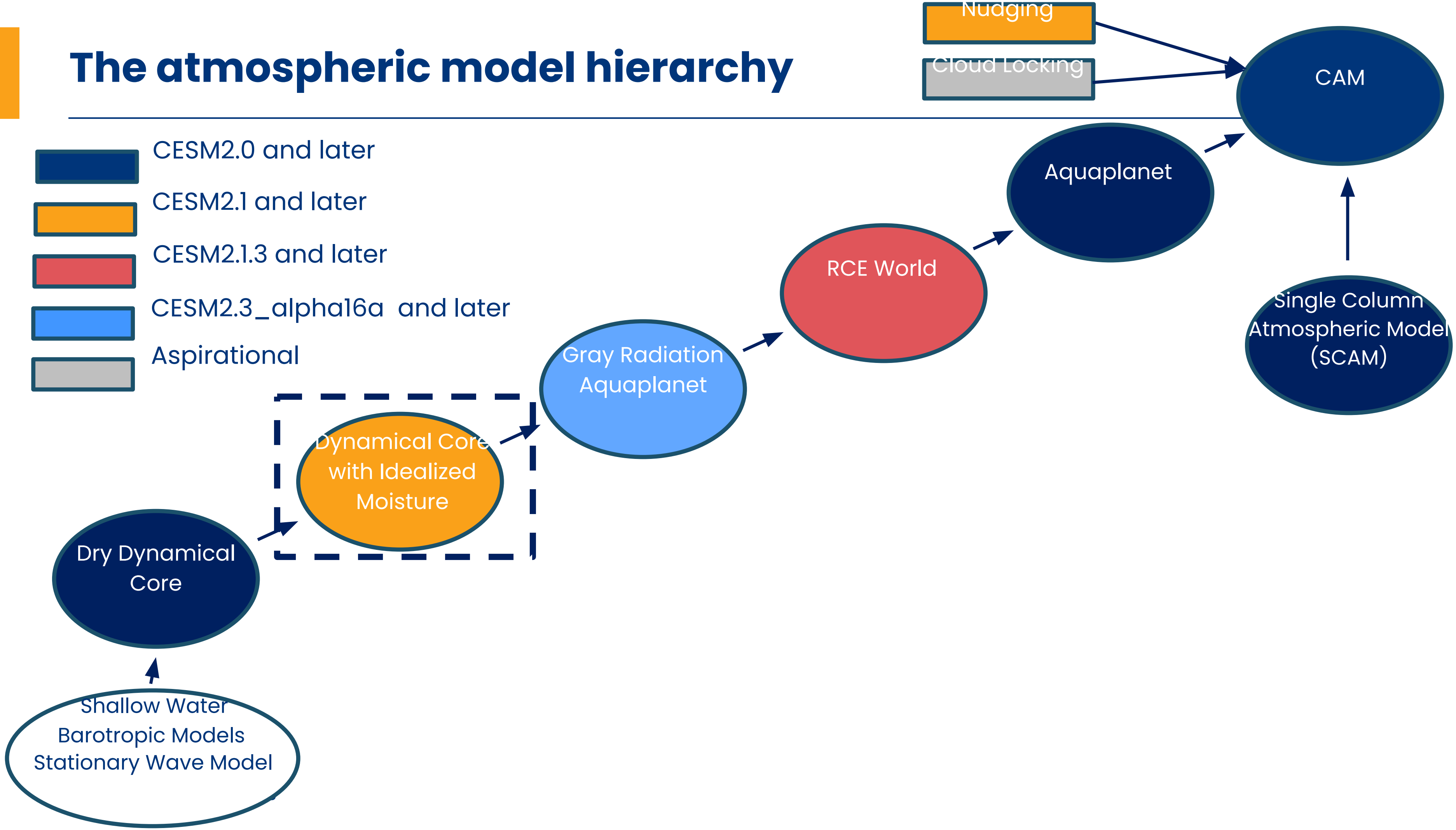


The atmospheric model hierarchy



Dry Dynamical Core

Dynamics

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Newtonian relaxation of the temperature field towards a specified equilibrium profile

$$\partial T = \ldots - T - T_{eq}$$

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$$\partial \vec{v} = \ldots - k\vec{v}$$

Dynamical Core With Idealized Moisture

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Water covered Earth

Prescribed SSTs

Evaporation

Heating associated with precipitation

The atmospheric mo

CESM2.0 and later

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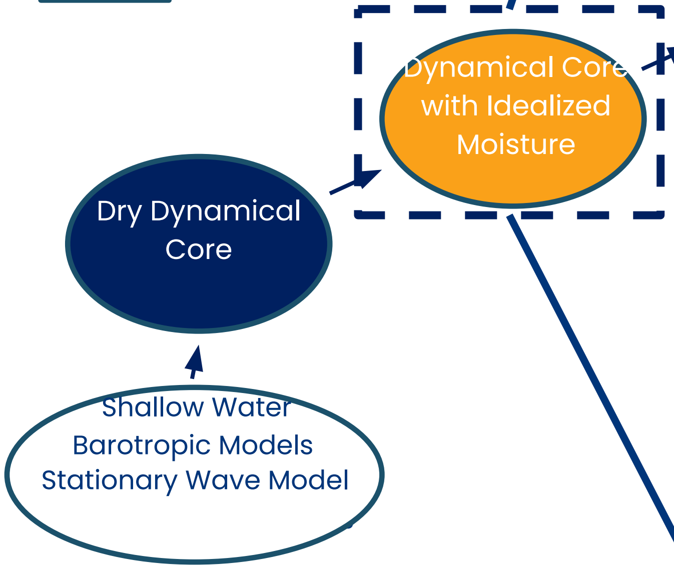


Moist Held-Suarez (Thatcher and Jablonowski 2016):
https://www.cesm.ucar.edu/models/simple/moist-held-suarez

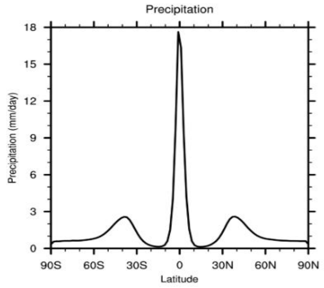
Like the dry dynamical core but with a representation of larg—scale condensation of moisture and associate diabatic heating

Newtonian relaxation of the temperature field

Moisture is advected by the large-scale circulation, condenses when it reaches saturation and immediately precipitates with 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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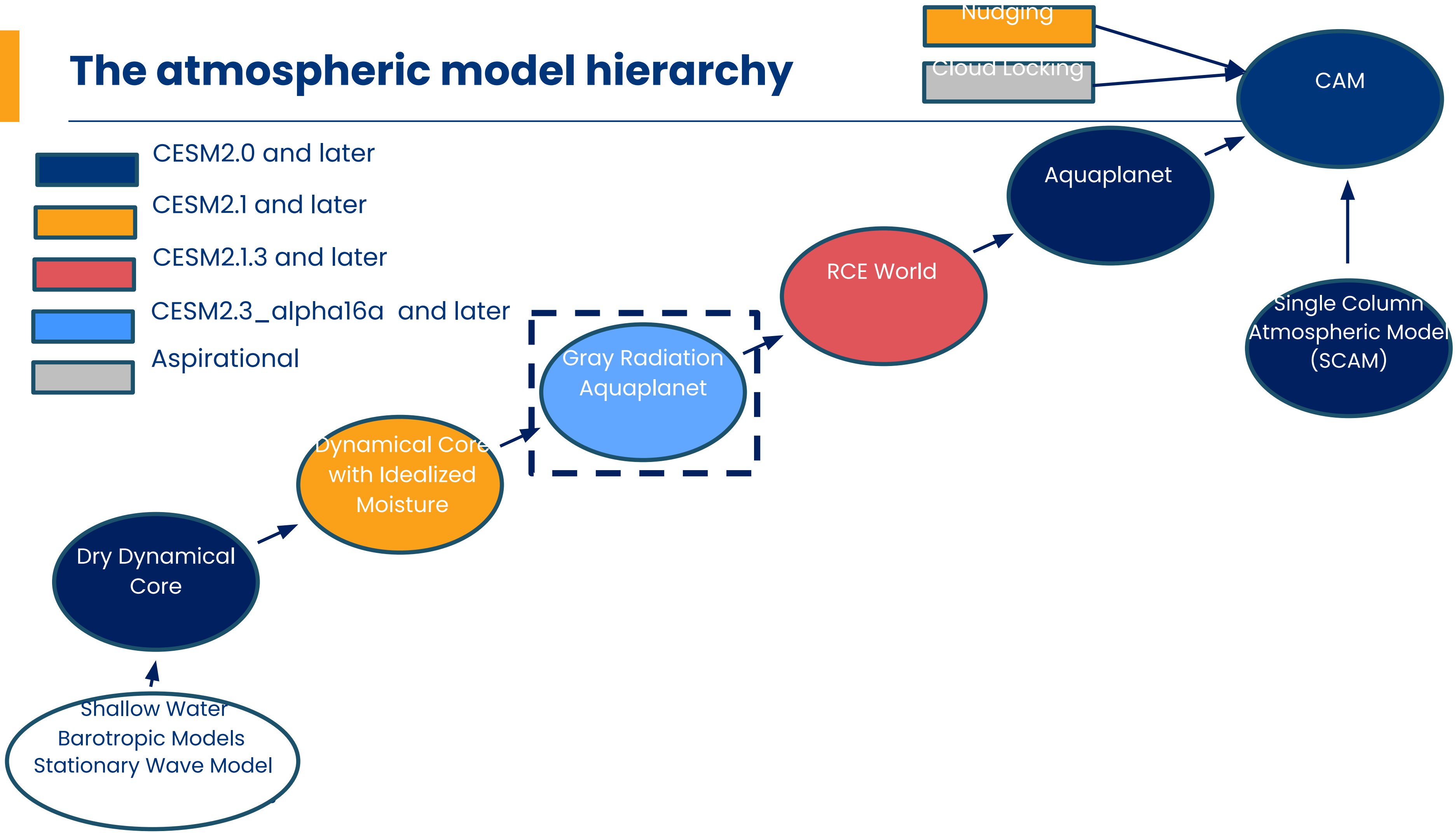

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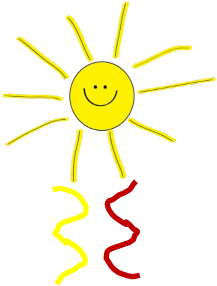

A simplified radiation scheme. Incoming shortwave. One longwave band with a specified longwave absorber. No clouds. Radiation scheme is not impacted by moisture.

Linear drag on winds at the lowest levels

$$\frac{\partial \vec{v}}{\partial t} = \ldots - k\vec{v}$$

Water covered Earth

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The atmospheric model hierarchy

- CESM2.0 and later
- CESM2.1 and later
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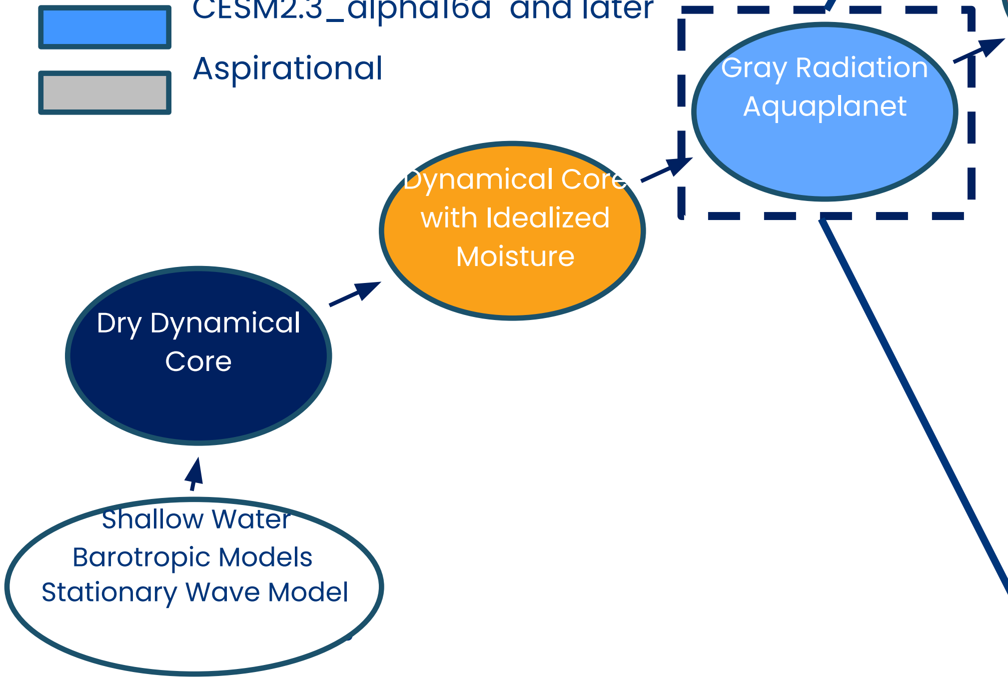
- CESM2.3_alpha16a and later
- Aspirational



Gray Radiation Aquaplanet:
https://www.cesm.ucar.edu/models/simple/gray-radiation-aquaplanet

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

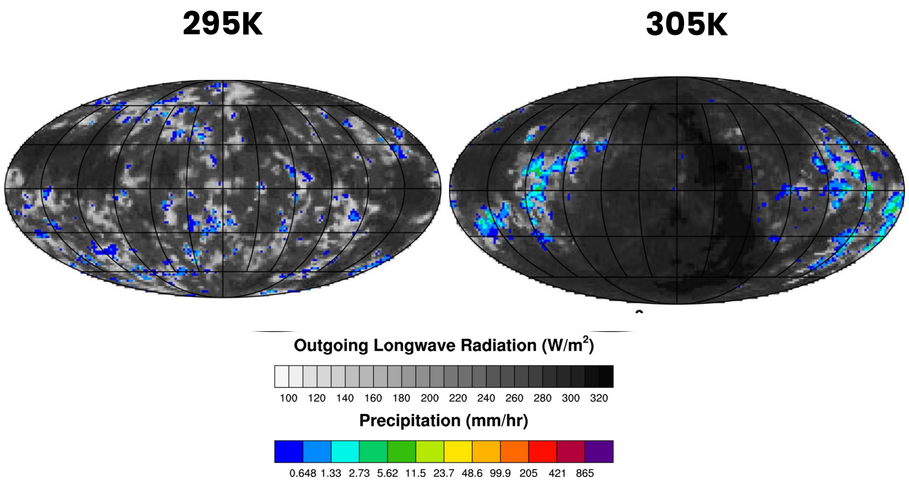
Good for idealized studies of the interaction between the circulation, radiation, and moisture

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

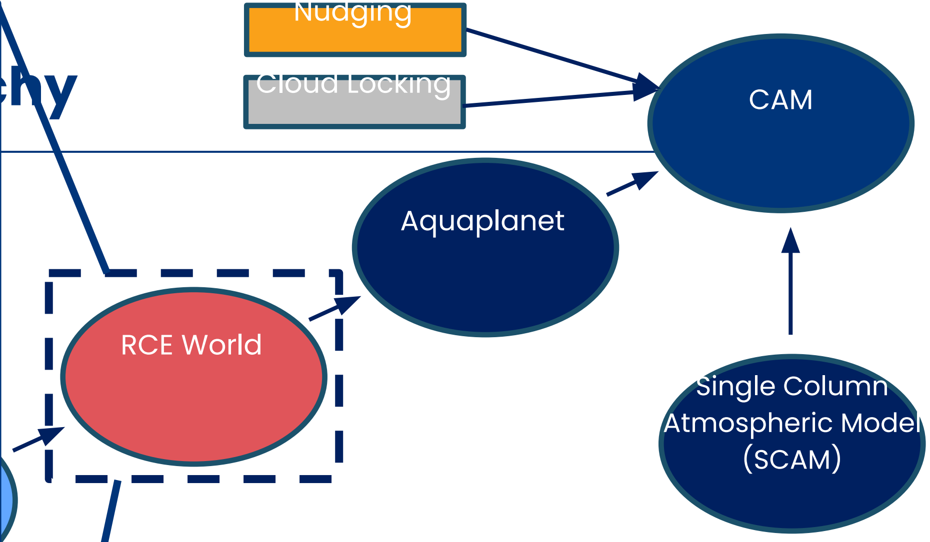
Compatible with the RCEMIP protocol

No rotation, uniform and constant insolation. Uniform prescribed SSTs

Planetary rotation and solar zenith angle can be specified



Reed et al. (2021)



Aquaplanet:

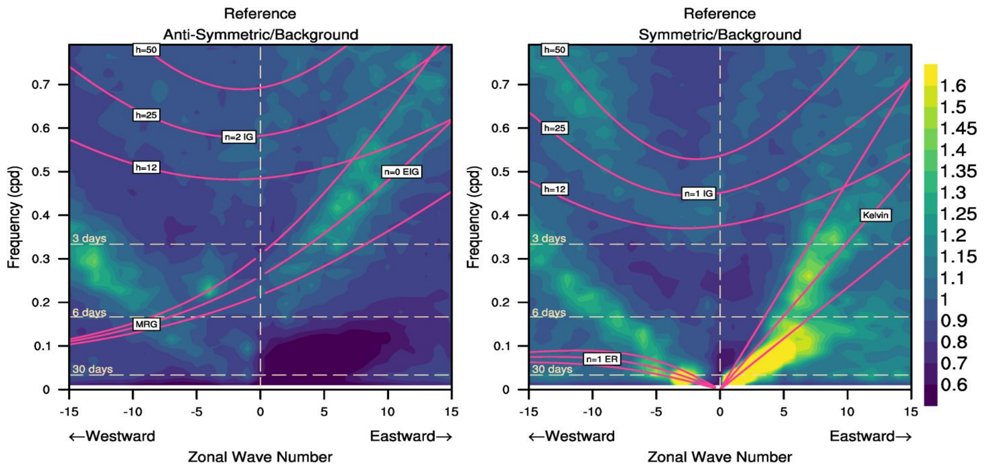
https://www.cesm.ucar.edu/models/simple/aquaplanet

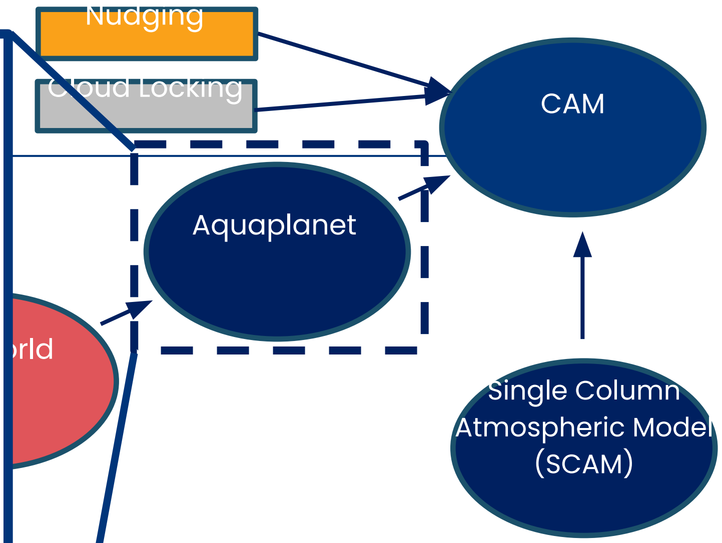
Full CAM4, CAM5, CAM6 physics. CAM7 coming.

Water covered Earth

Prescribed SSTs or slab ocean

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

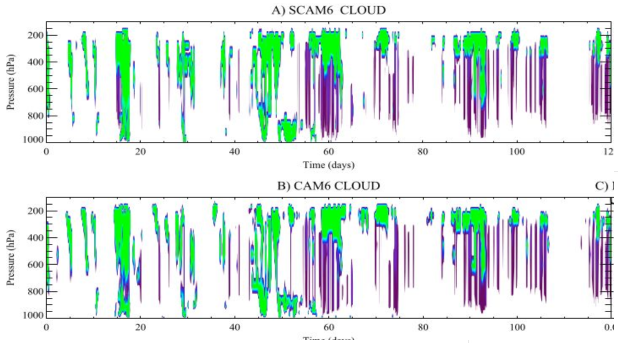




Single Column Atmospheric Model (SCAM), Gettelman et al. 2019: https://www.cesm.ucar.edu/models/simple/scam

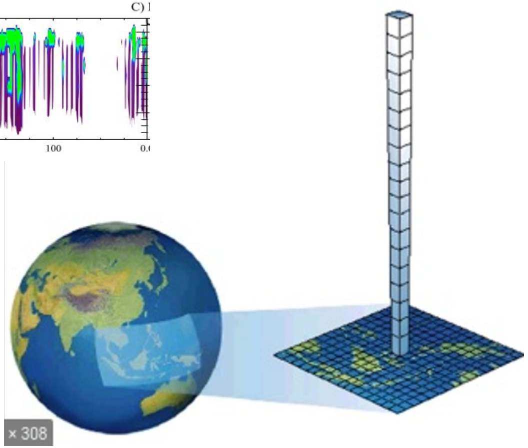
Full CAM physics

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



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



Nudging

Cloud Locking

CAM

Aquaplanet

Single Column Atmospheric Model (SCAM)

Land Simpler Models

SLIM (The Simple Land Interface Model)

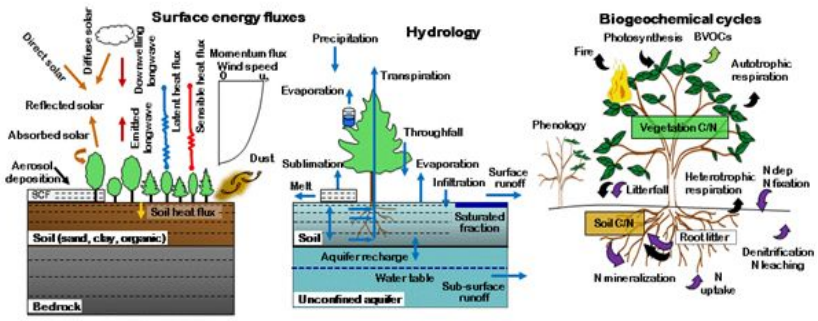
Solves linearized bulk surface energy budget coupled with soil temperatures and bucket hydrology.

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

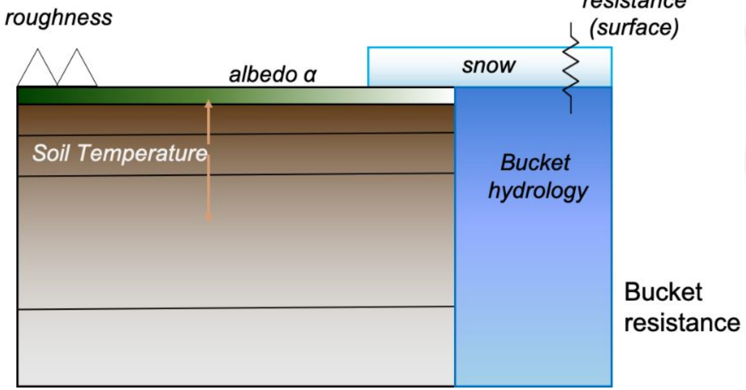
Allows for much more flexibility in prescribing land surface properties as opposed to letting them emerge as a result of the biophysics in CLM.

Marysa Lague. Abby Swann Gordon Bonan Erik Kluzek

CLM5



SLIM

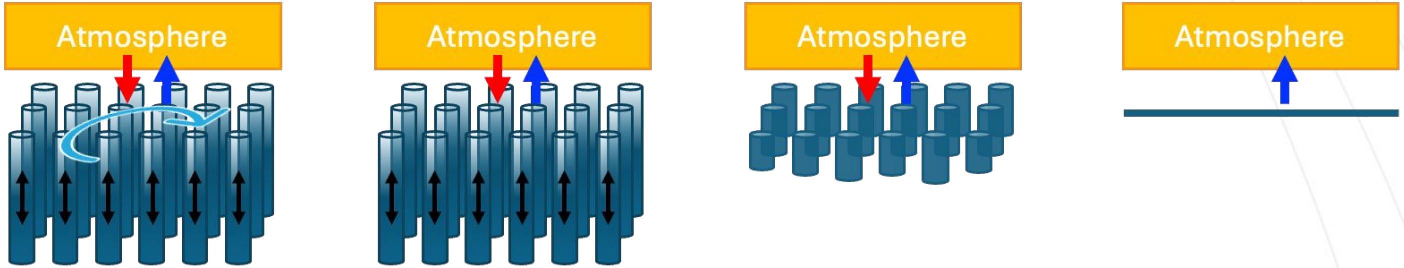


Aiming for release in CESM3 or very soon after

Ocean Simpler Models

The Multi-Column ocean model

Ocean Model Hierarchy



Full 3-D Ocean Model (FOM; POP2)

Multi-Column Ocean Model (MCOM; array of 1-D ocean columns)

Slab Ocean Model (SOM)

Data Ocean

Role of ocean lateral processes

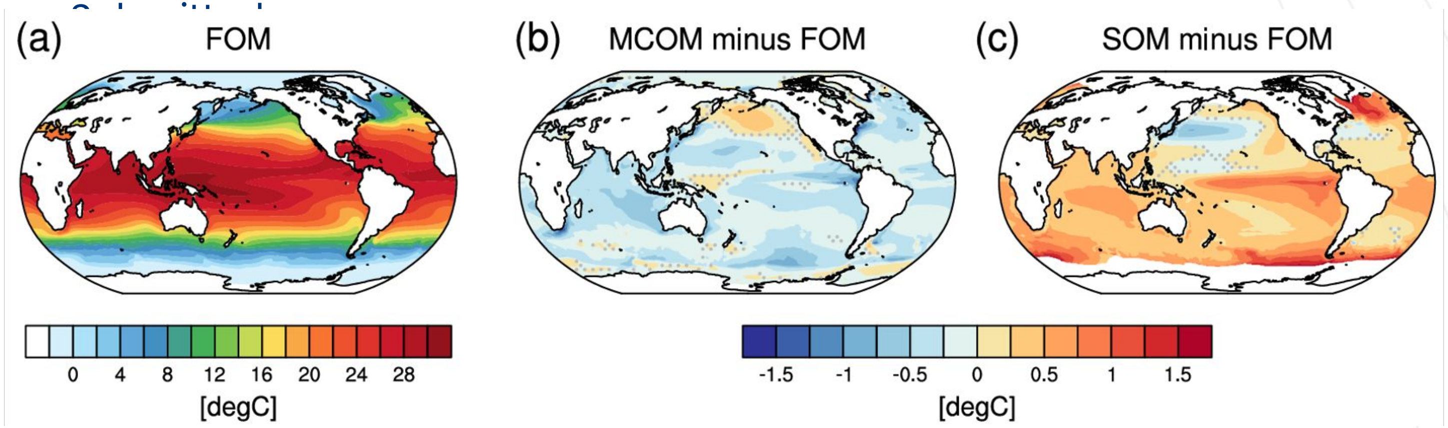
Role of ocean vertical mixing and mixed layer variability

Now implemented in CESM2 (uses POP)
Not yet documented on the simpler models website

Point of contact: Young-Oh Kwon, WHOI

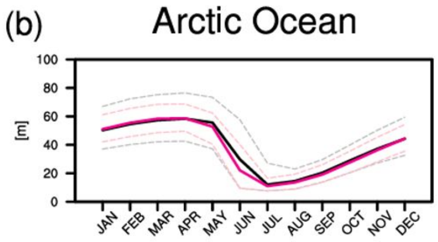
The Multi-Column ocean model

Shin, J., Y.-O. Kwon, G. Danabasoglu, M. N. Levy, Y.-C. Liang, I. D. Lima, G. Liu, Y.-H. Tseng: Multi-column Ocean Model (MCOM): A New 1-Dimensional Ocean Model in CESM2, *J. Adv. Mod. Earth Sys.*,



SST climatology is better represented in MCOM than SOM

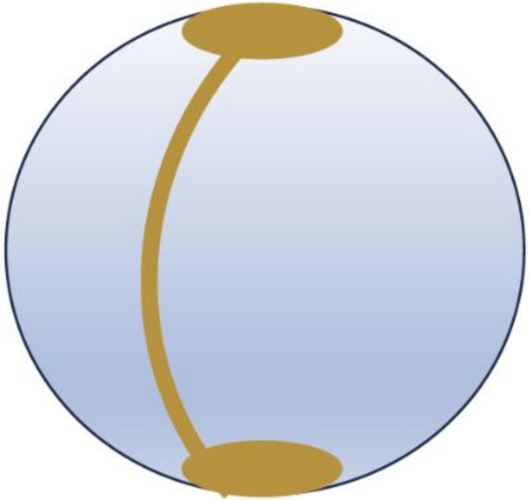
Seasonal cycle of the mixed layer depth in MCOM is well represented in many regions, except near the equator



Coupled Idealized Modeling

visualCaseGen

A GUI for setting up CESM cases, with tools for changing land-surface properties, continental geometry, and ocean bathymetry: https://esmci.github.io/visualCaseGen/



Ridge World

Developed by Alper Altuntas

visualCaseGen

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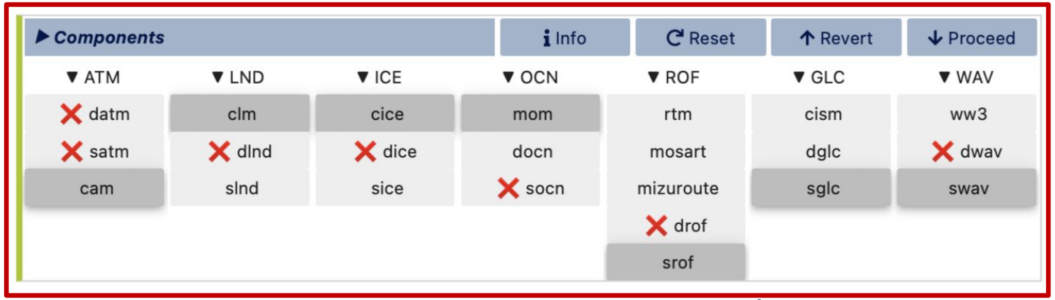

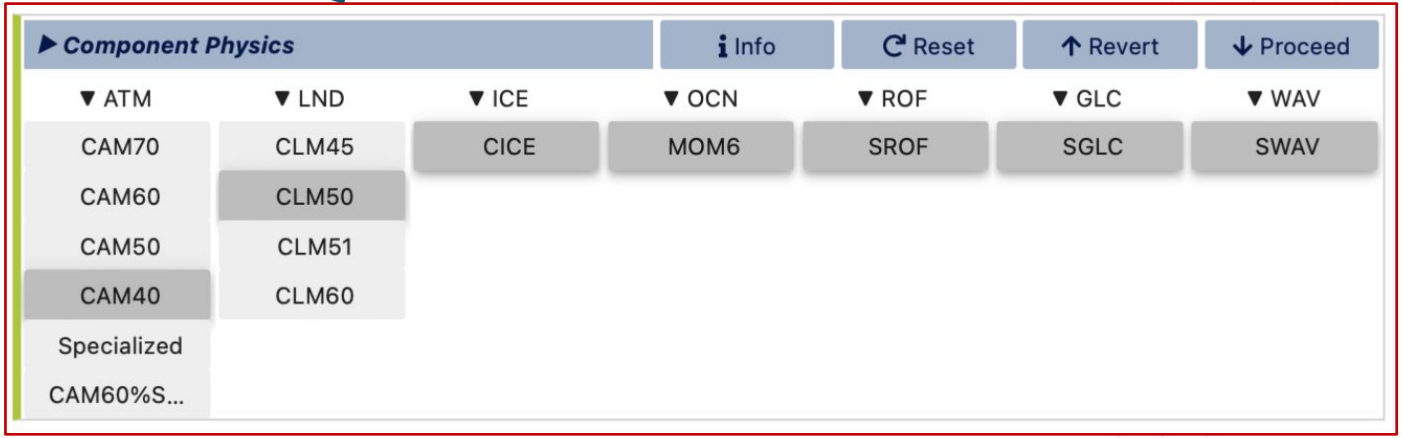

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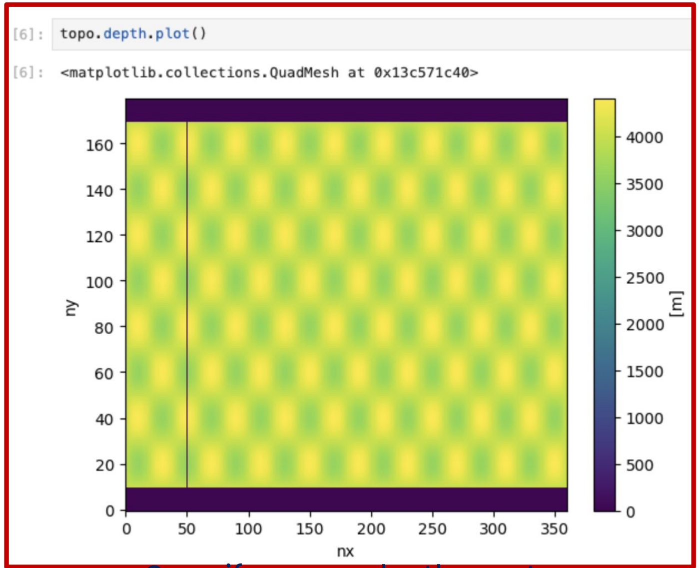
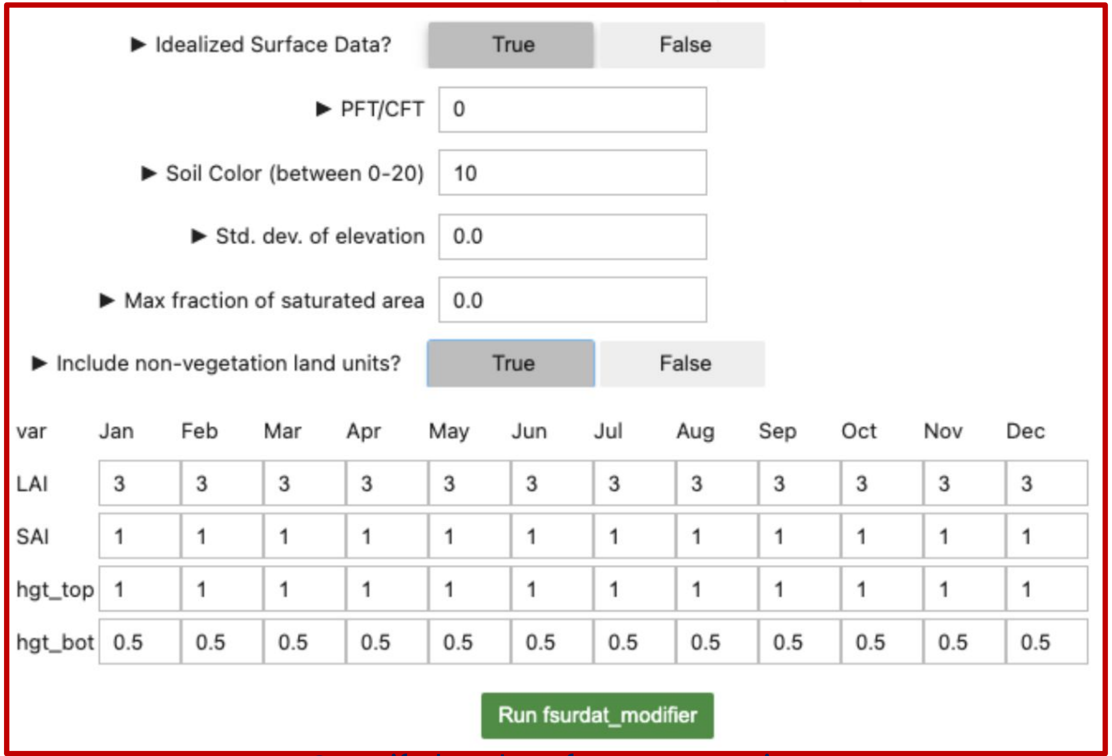


Specify ocean bathymetry

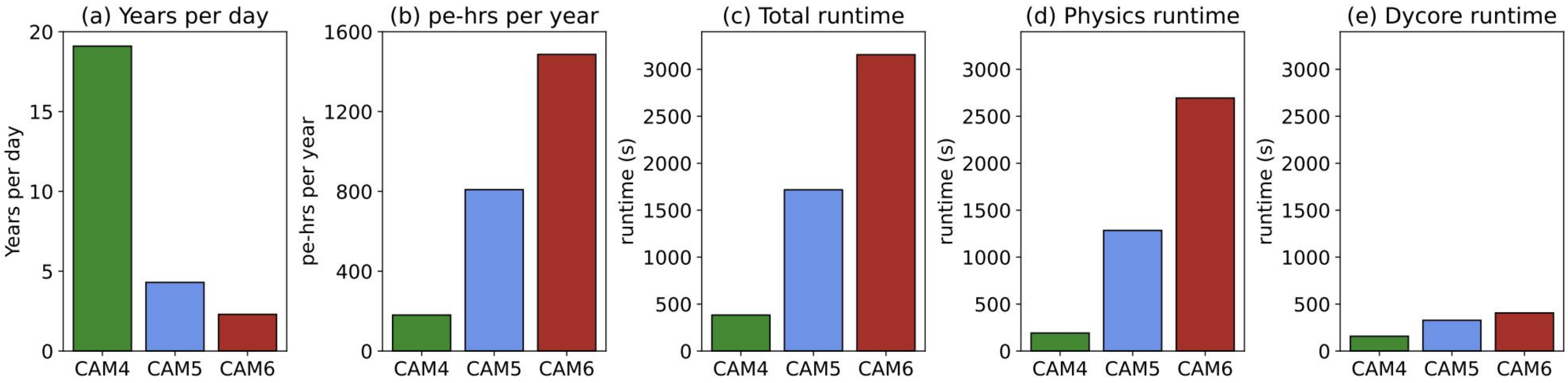


Specify land surface properties

Cheaper/Faster Comprehensive Physics

Maintaining CAM4 and CAM5 capabilities

CAM has become more and more expensive over time. Depending on the application, the cheaper faster older CAM physics options may still be appropriate.



Coming soon thanks to NSF cyberinfrastructure funding: CAM4 and CAM5 capabilities will be maintained within CESM3 moving forward. Still under development. Hoping to provide guidance as to strengths and weaknesses of these physics options in the coming year.

Conclusions

A wide variety of idealized configurations and options for configuring comprehensive CESM in an idealized way are available.

Some of them area really cheap to run. You can even run them on your laptop

Check out the simpler models website for details: https://www.cesm.ucar.edu/models/simple

Post queries to the CESM forum under simpler models: https://bb.cgd.ucar.edu/cesm/forums/simpler-models.161/

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