Simpler models within the CESM framework

OMWG webinar (Jul 6th)

Isla Simpson, Scott Bachman

People (in alphabetical order):

Scott Bachman, Jim Benedict, Frank Bryan, Patrick Callaghan, Amy Clement, Cheryl Craig, Brian Dobbins, Brian Eaton, Andrew Gettelman, Christiane Jablonowski, Peter Lauritzen, Steve Goldhaber, Brian Medeiros, Lorenzo Polvani, Kevin Reed, Isla Simpson, John Truesdale, Mariana Vertenstein, Xaoning Wu

NCAR

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Why is there a need for “Simpler Models”?

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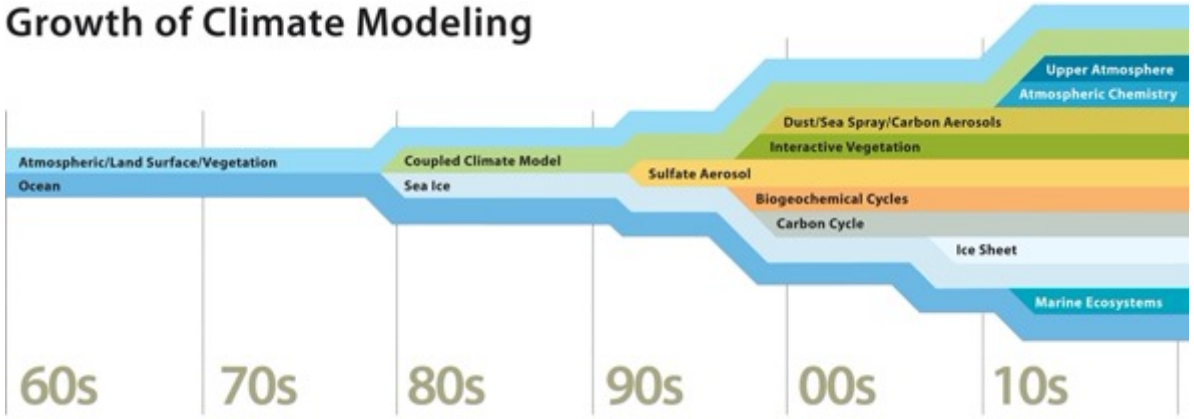
- Earth System Models are continually increasing in complexity

  "The health of climate theory/modelling in the coming decades is threatened by a growing gap between high-end simulations and idealized theoretical work. In order to fill this cap, research with a hierarchy of models is needed" – Held (2005), BAMS



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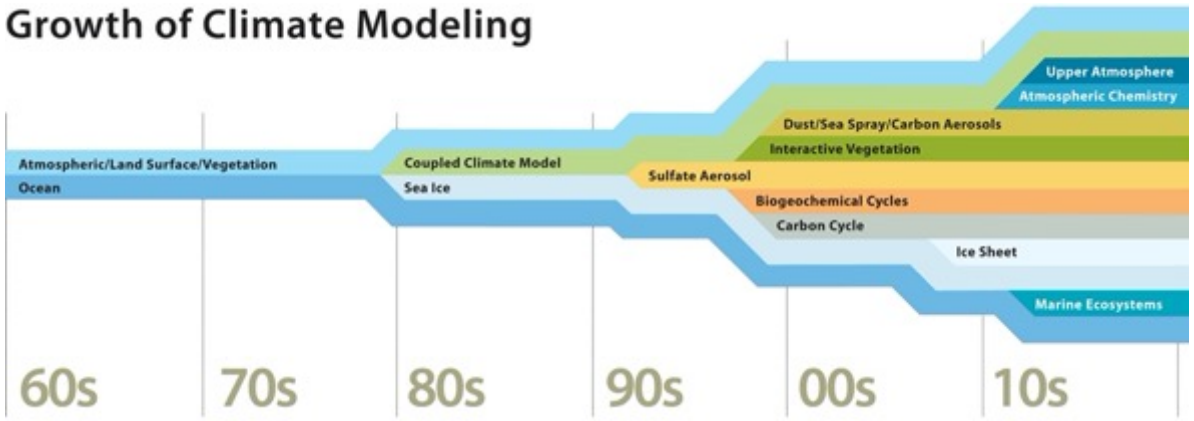
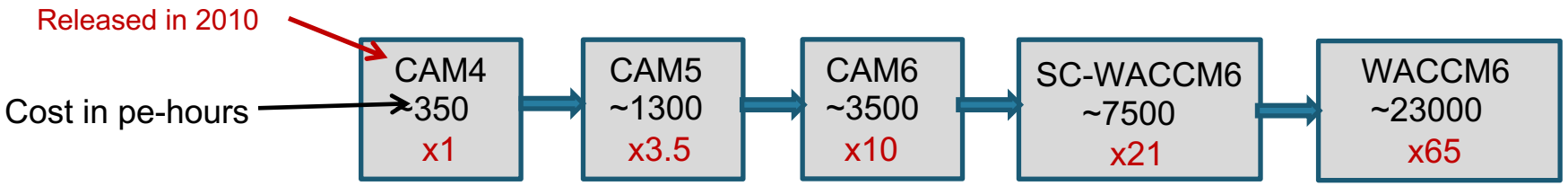


- This increase in complexity typically comes with increased computational cost



→ Challenging to perform sensitivity tests, parameter sweeps etc needed for understanding and/or model development.

Two partially overlapping user groups

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Climate Dynamicists

- Looking to gain a comprehensive theoretical understanding of the full system
- Simpler models are cheap to run
- Simpler models are easy to perturb

→ Allows for many perturbation experiments and parameter sweeps to explore sensitivities and gain that theoretical understanding in an idealized setting

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Model developers

- Idealized test cases for model numerics/tracer transports etc
- Debugging during dynamical core or physics parameterization development
- Explore tuning sensitivities
- Intercomparison of model components in an idealized setting

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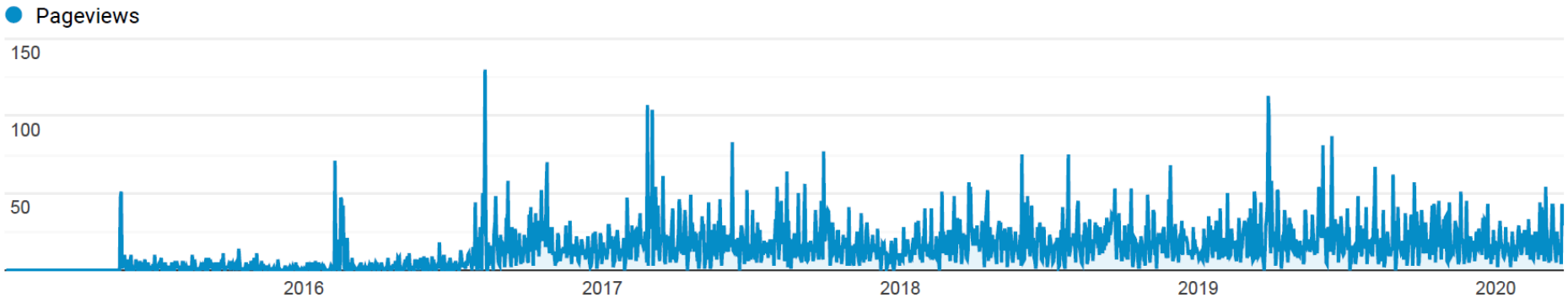
Google analytics page views of all CESM simpler models web-pages



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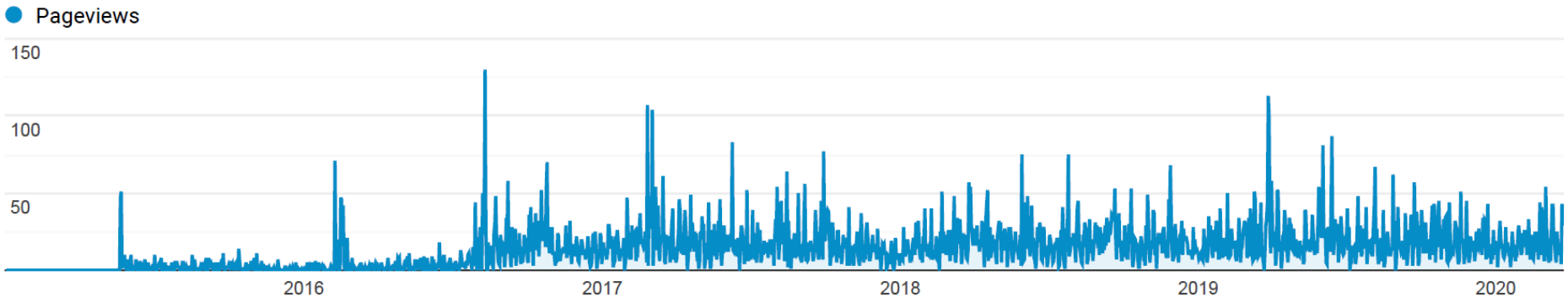

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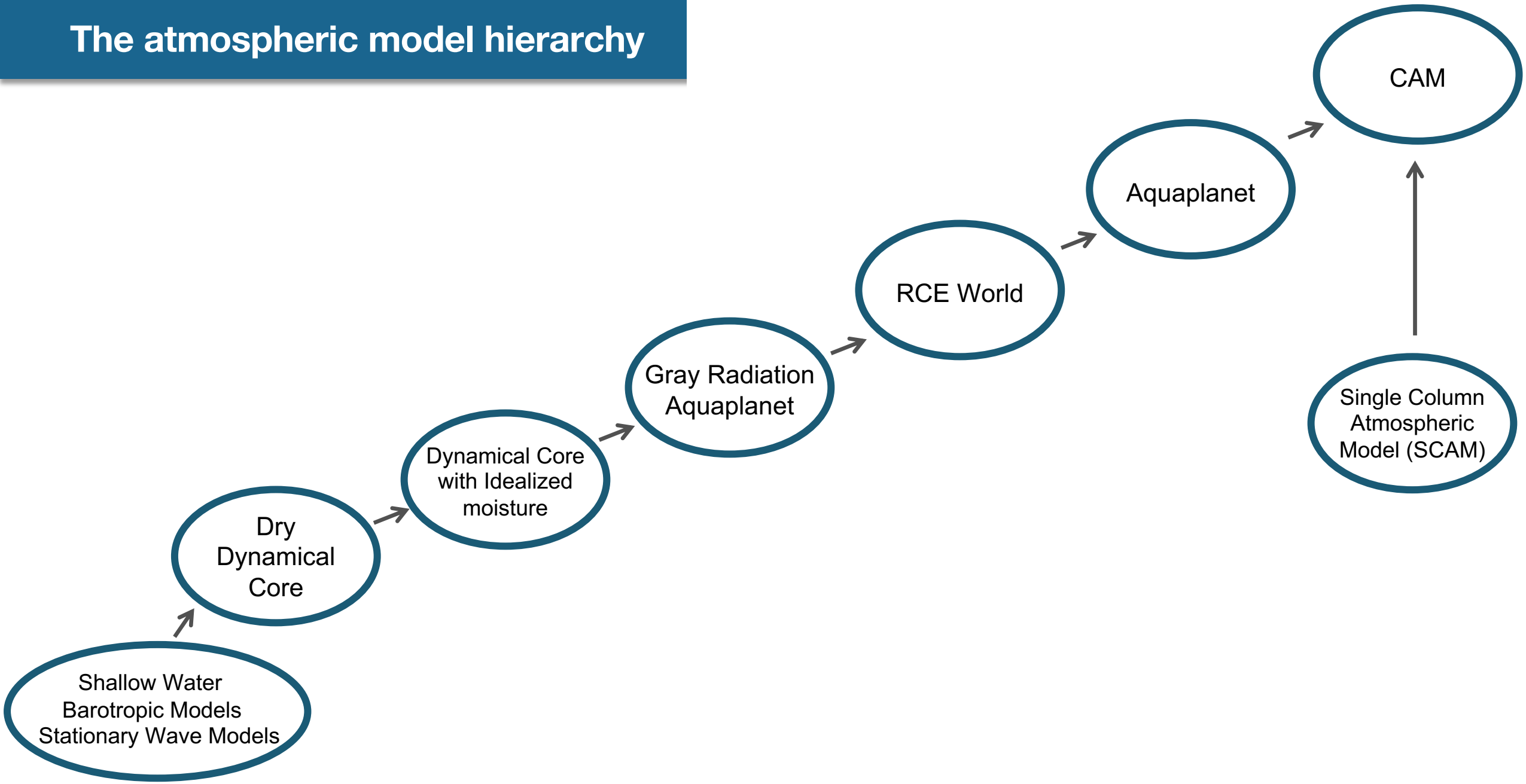
- The number of available configurations is growing steadily

Atmospheric idealized modelling

The atmospheric model hierarchy



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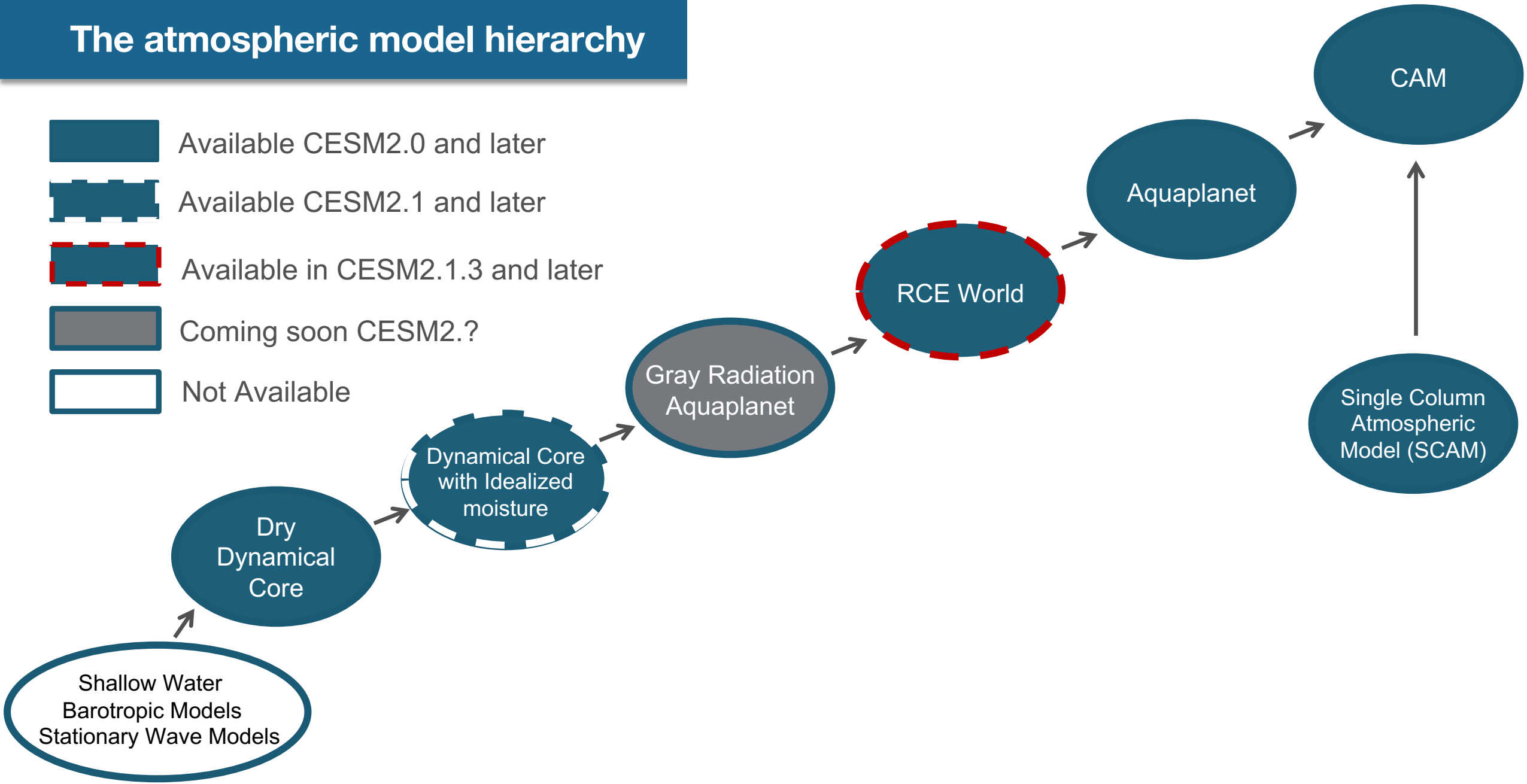

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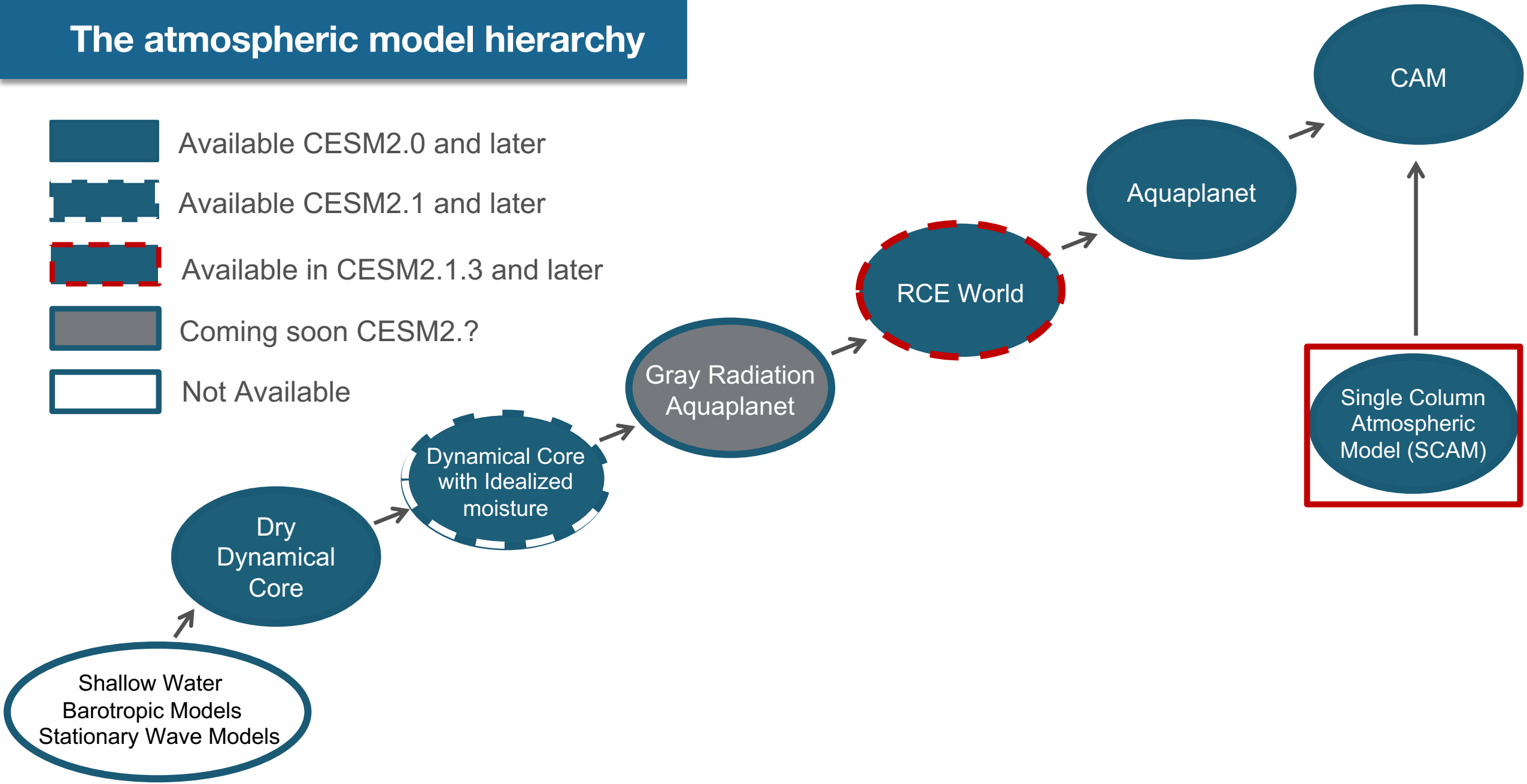
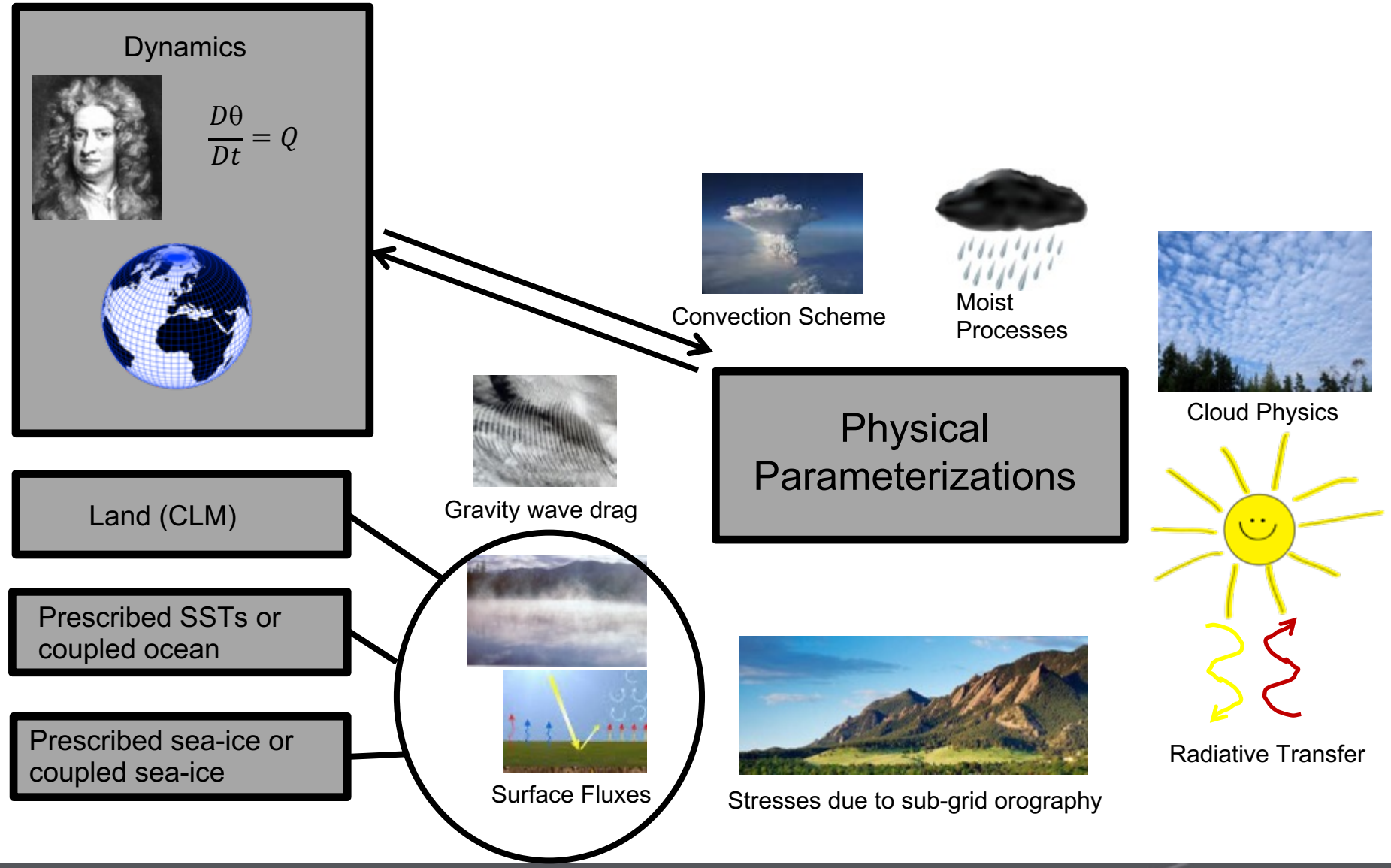


Single Column Atmospheric Model



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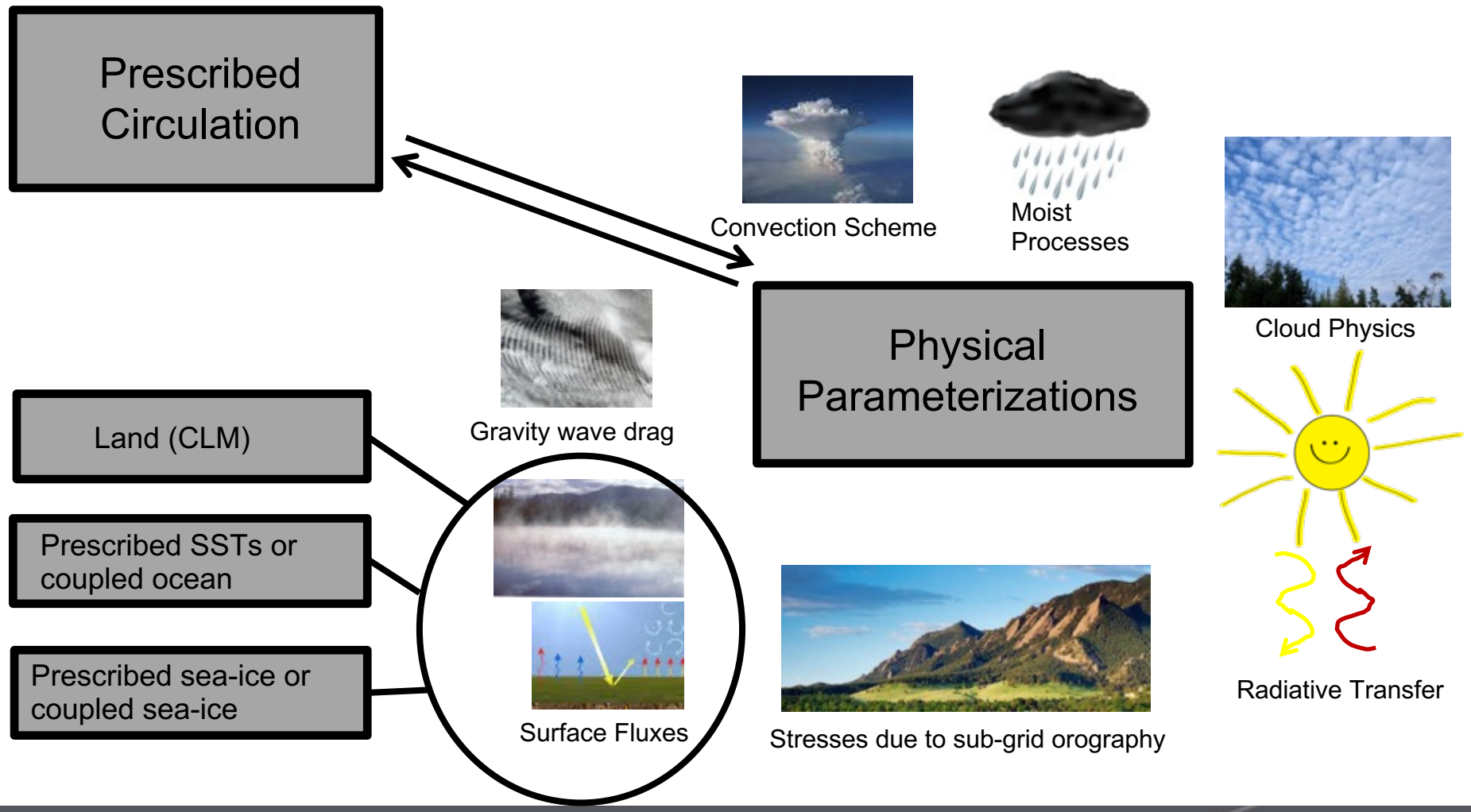
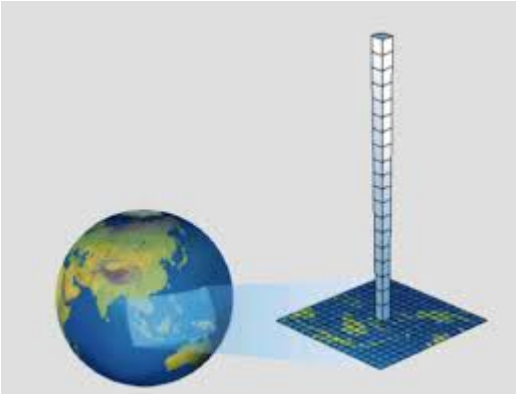


The Single Column Atmospheric Model (SCAM)

(Andrew Gettelman and John Truesdale)



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Fully functioning in CESM2.

Containerized version also available with accompanying jupyter lab tutorial and visualization tool (Brian Dobbins)

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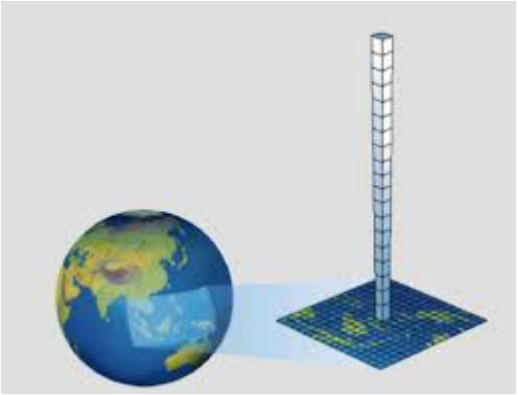

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A couple SCAM is also under development (SCESM) – Andrew Gettelman and John Truesdale

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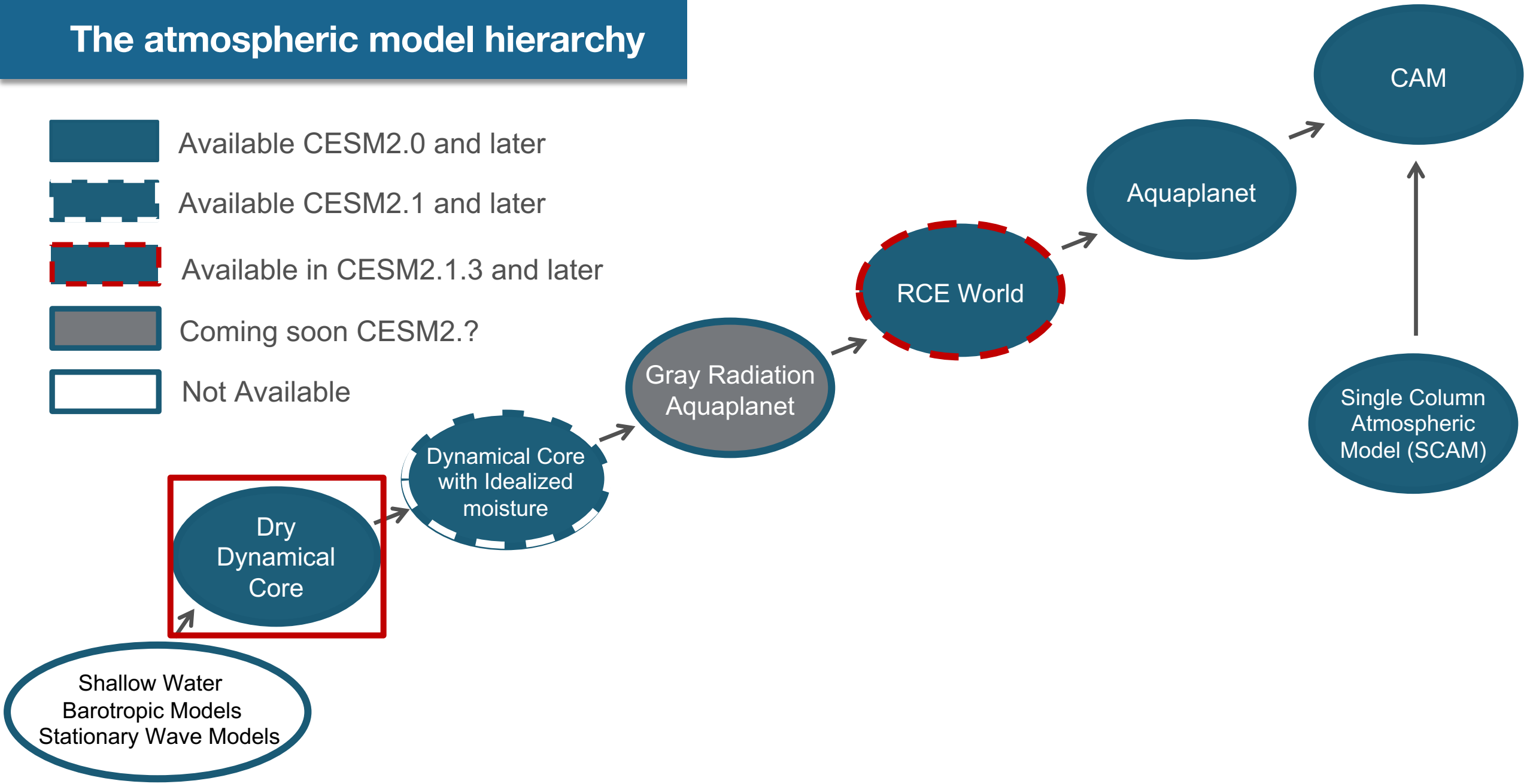
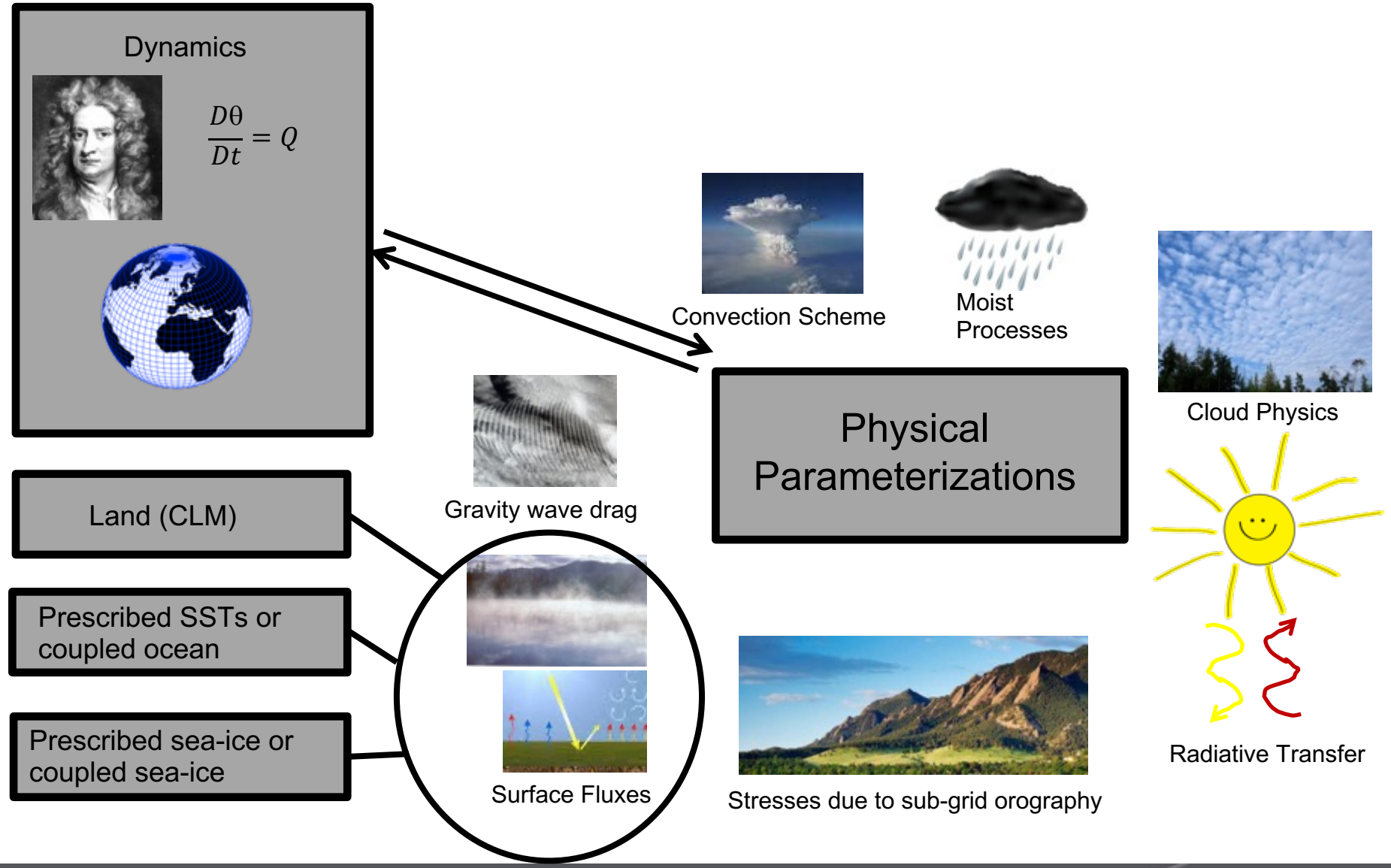


Dry dynamical core, Held-Suarez configuration



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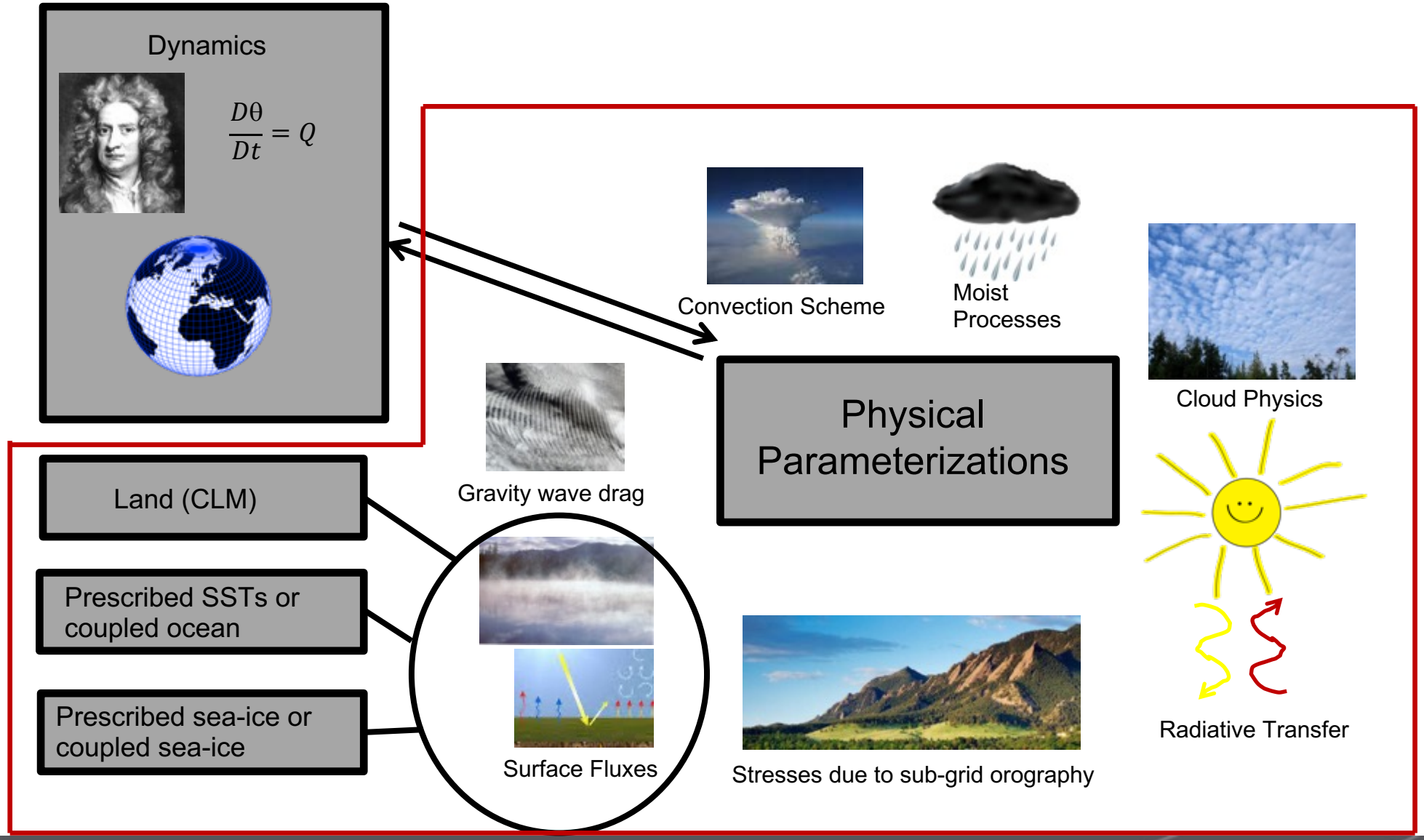

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Dynamics

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

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

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

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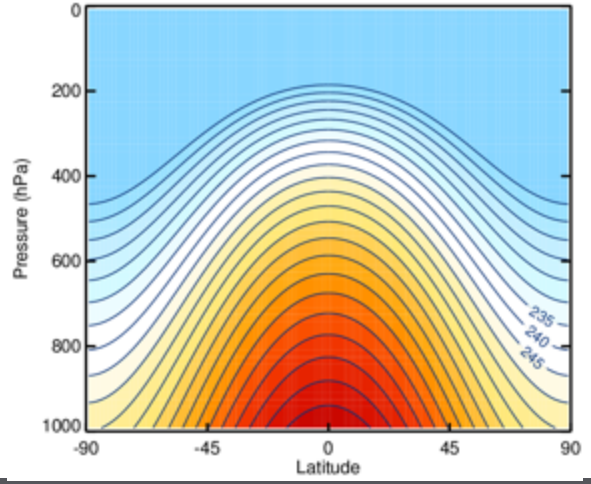

Following Held and Suarez (1994)

A Proposal for the Intercomparison of the Dynamical Cores of Atmospheric General Circulation Models

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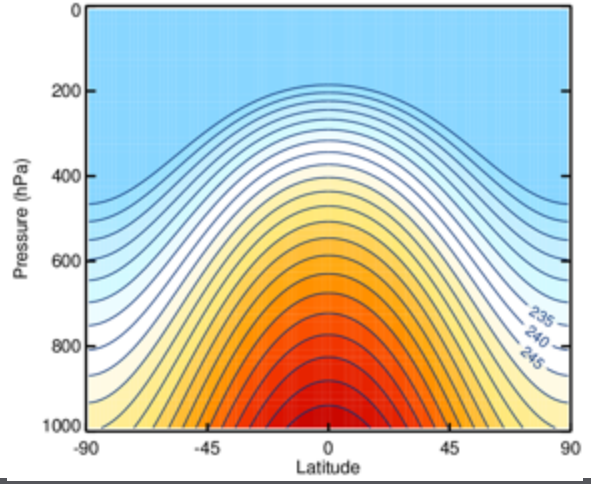

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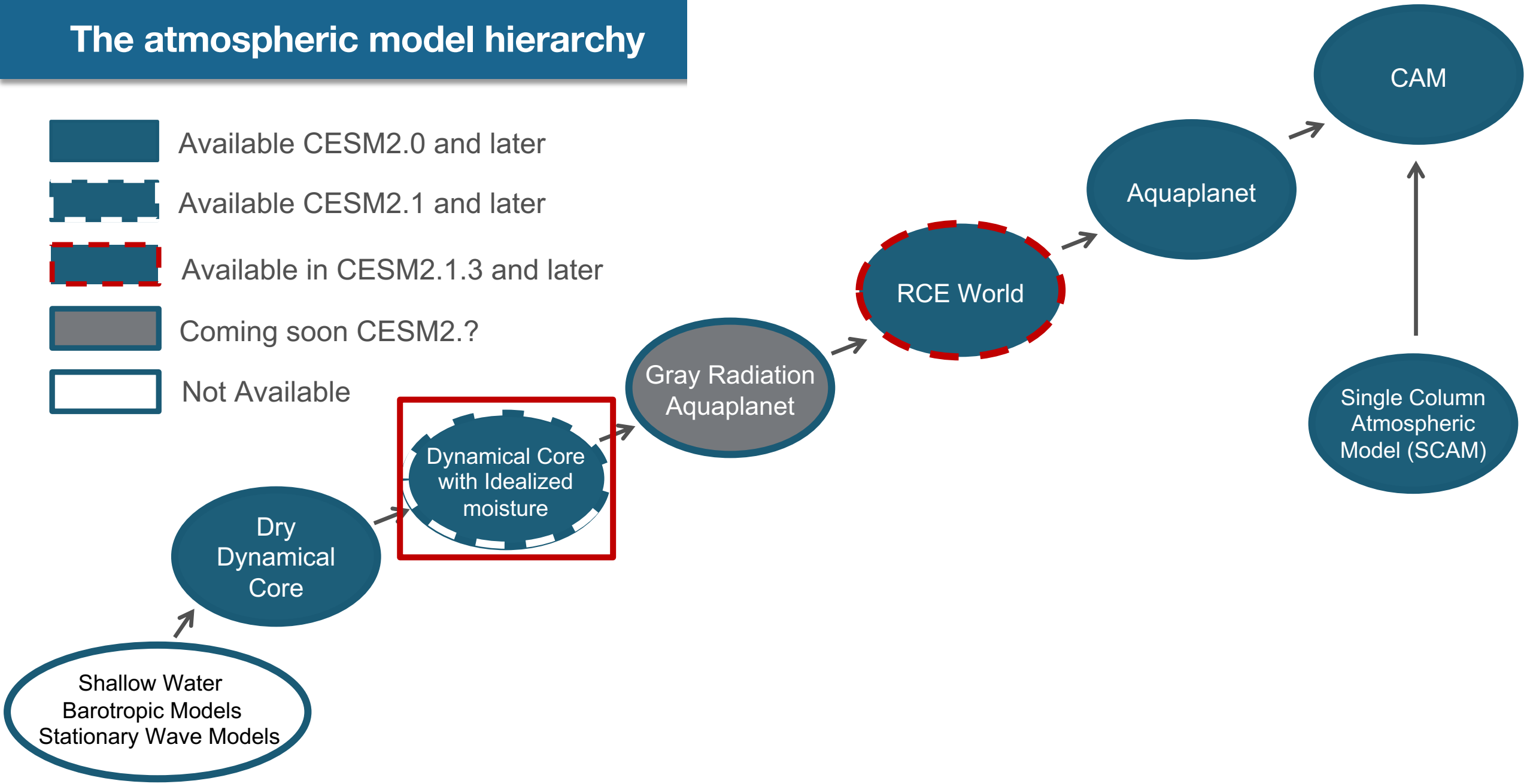

Moist Held-Suarez (Thatcher and Jablonowski 2016)

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Dynamics

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

Newtonian Relaxation of the Temperature field toward a specified equilibrium profile

$$\frac{\partial T}{\partial t} = \cdots - \frac{T - T_{EQ}}{\tau} + Q$$

Linear drag on wind at the lowest levels

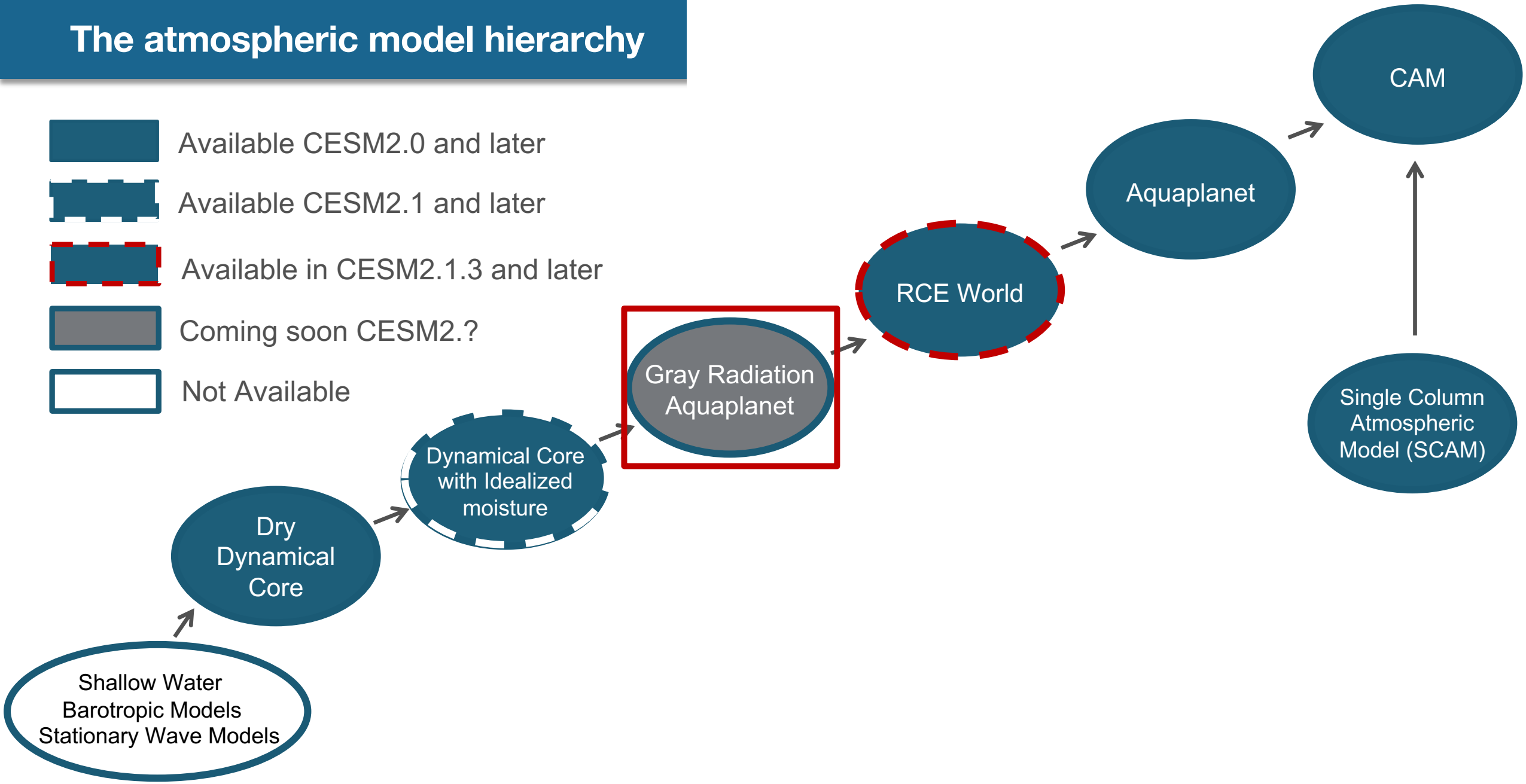
$$\frac{\partial \vec{v}}{\partial t} = \cdots - k_v \vec{v}$$

Evaporation from a water covered Earth using simple bulk formulae

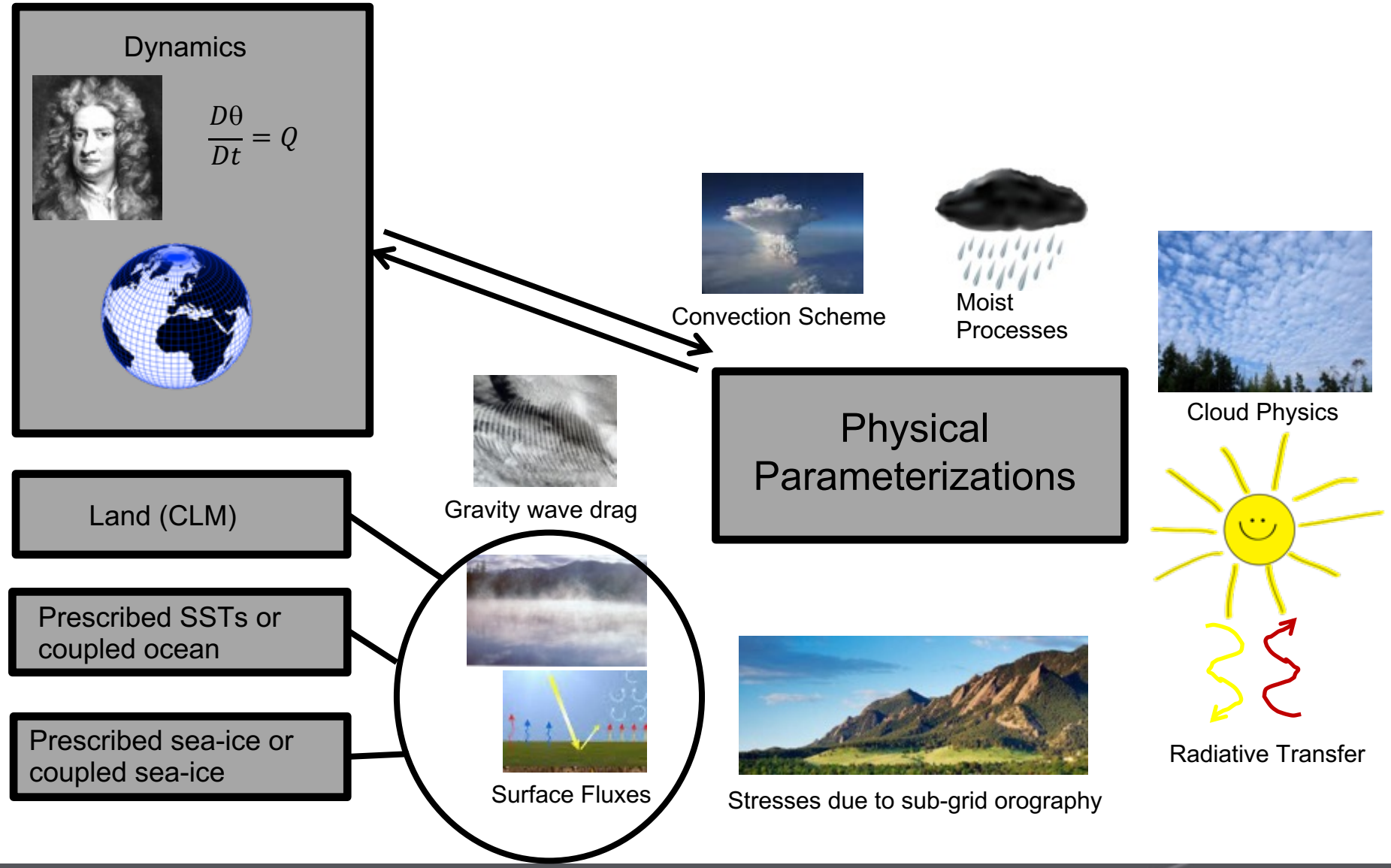
Moisture moves around with the circulation

When specific humidity > 100% relative humidity → condensation and precipitation with associated diabatic heating

The atmospheric model hierarchy



Gray Radiation Aquaplanet (Frierson et al 2006)



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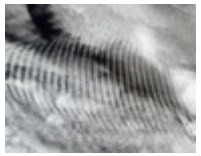
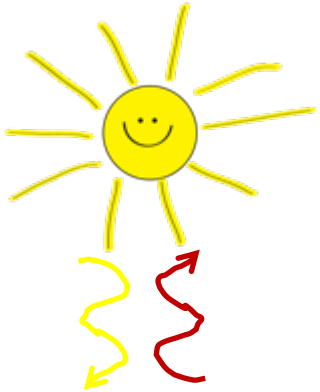
Cloud Physics

Physical Parameterizations

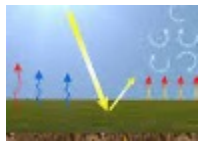


Gravity wave drag



Radiative Transfer

Slab ocean aquaplanet



Surface Fluxes

Stresses due to sub-grid orography

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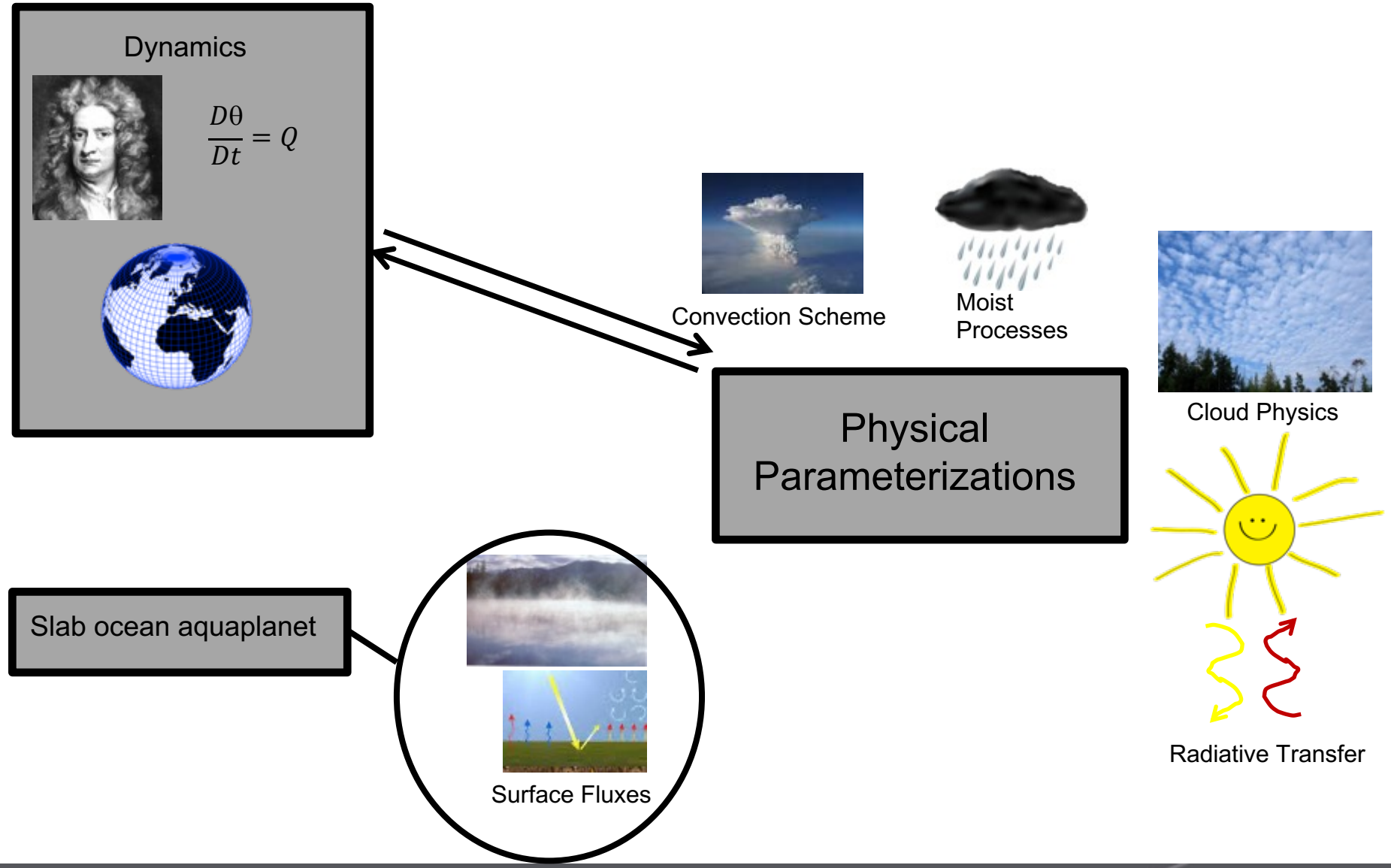

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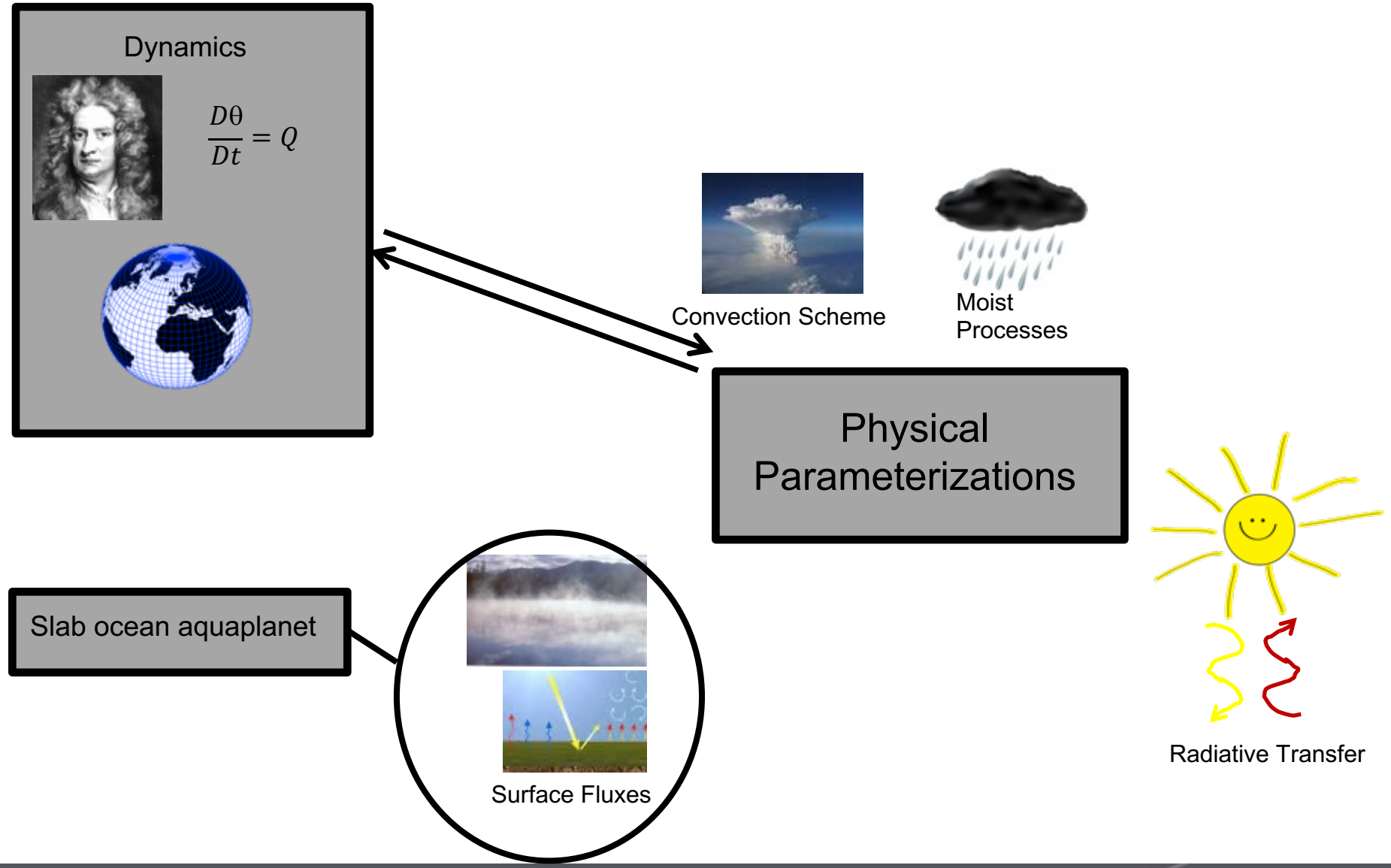

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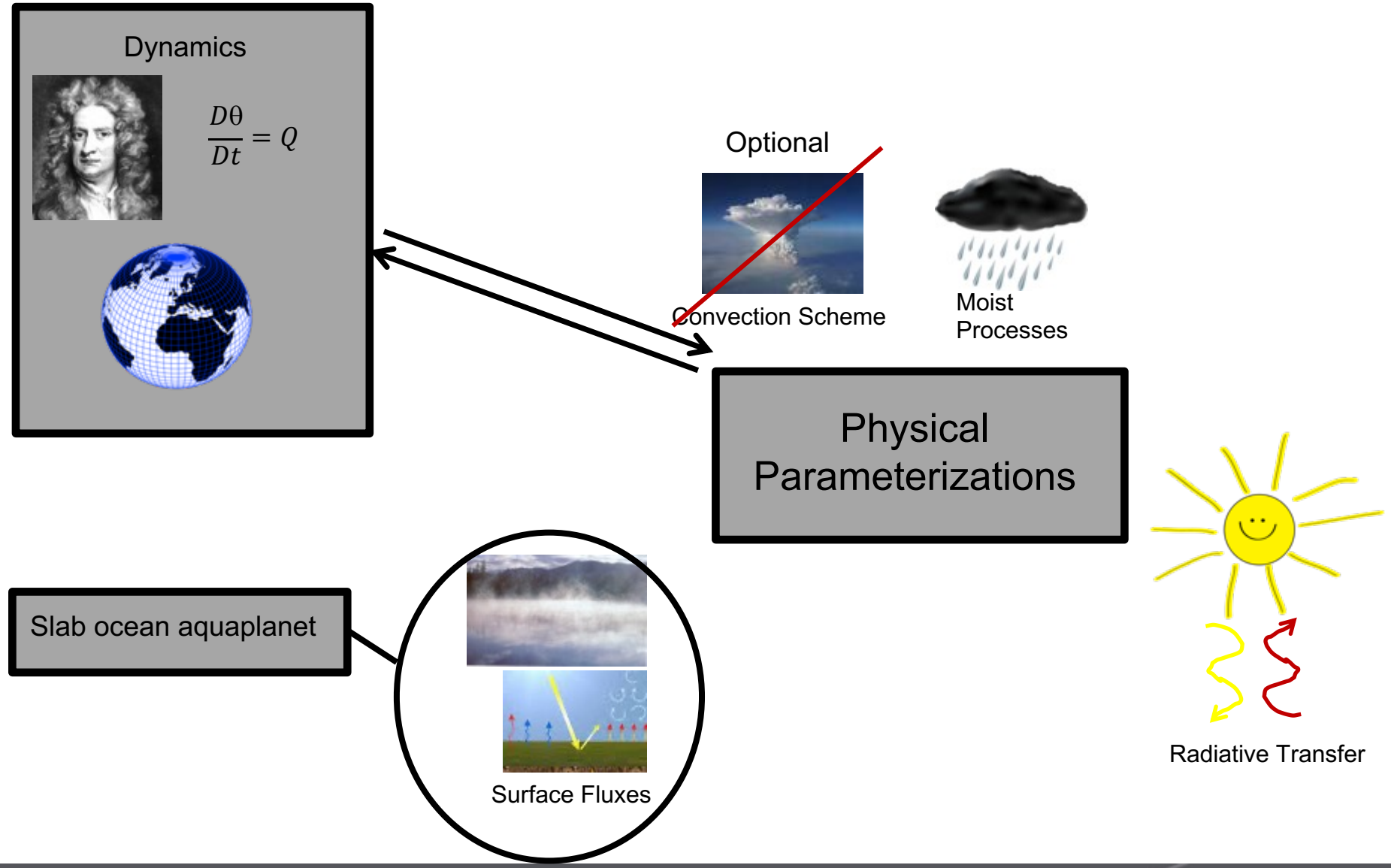

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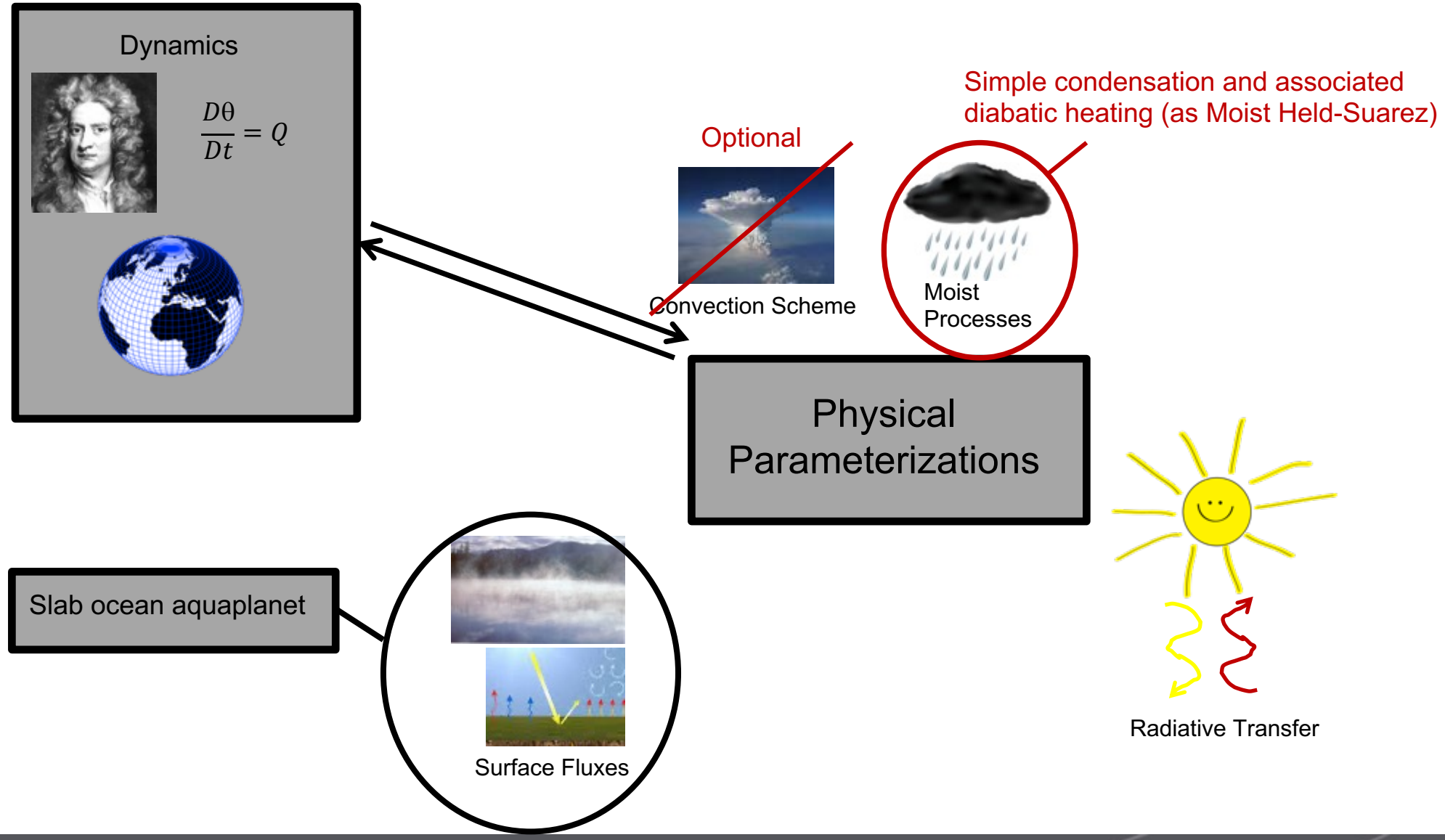

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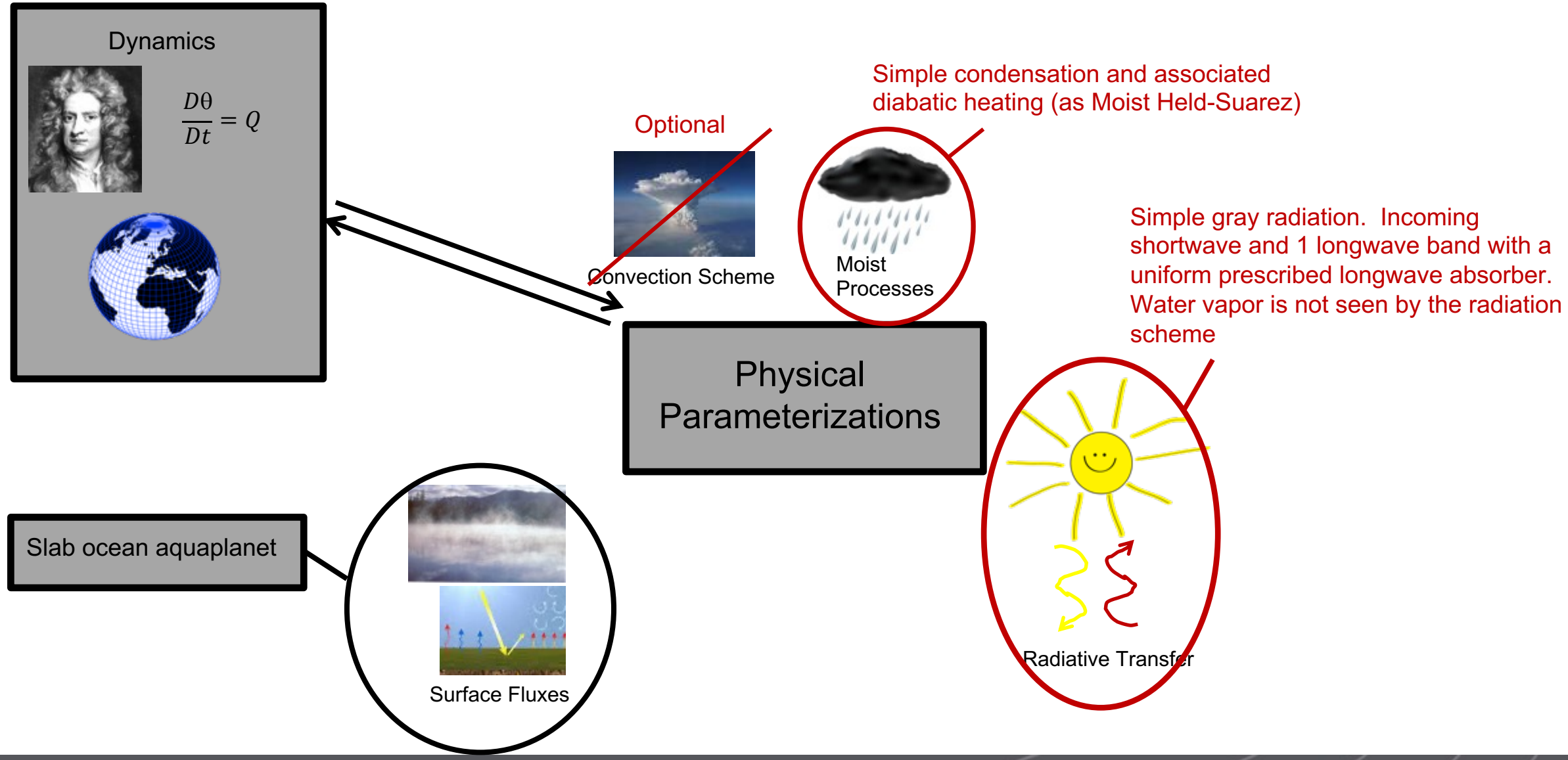
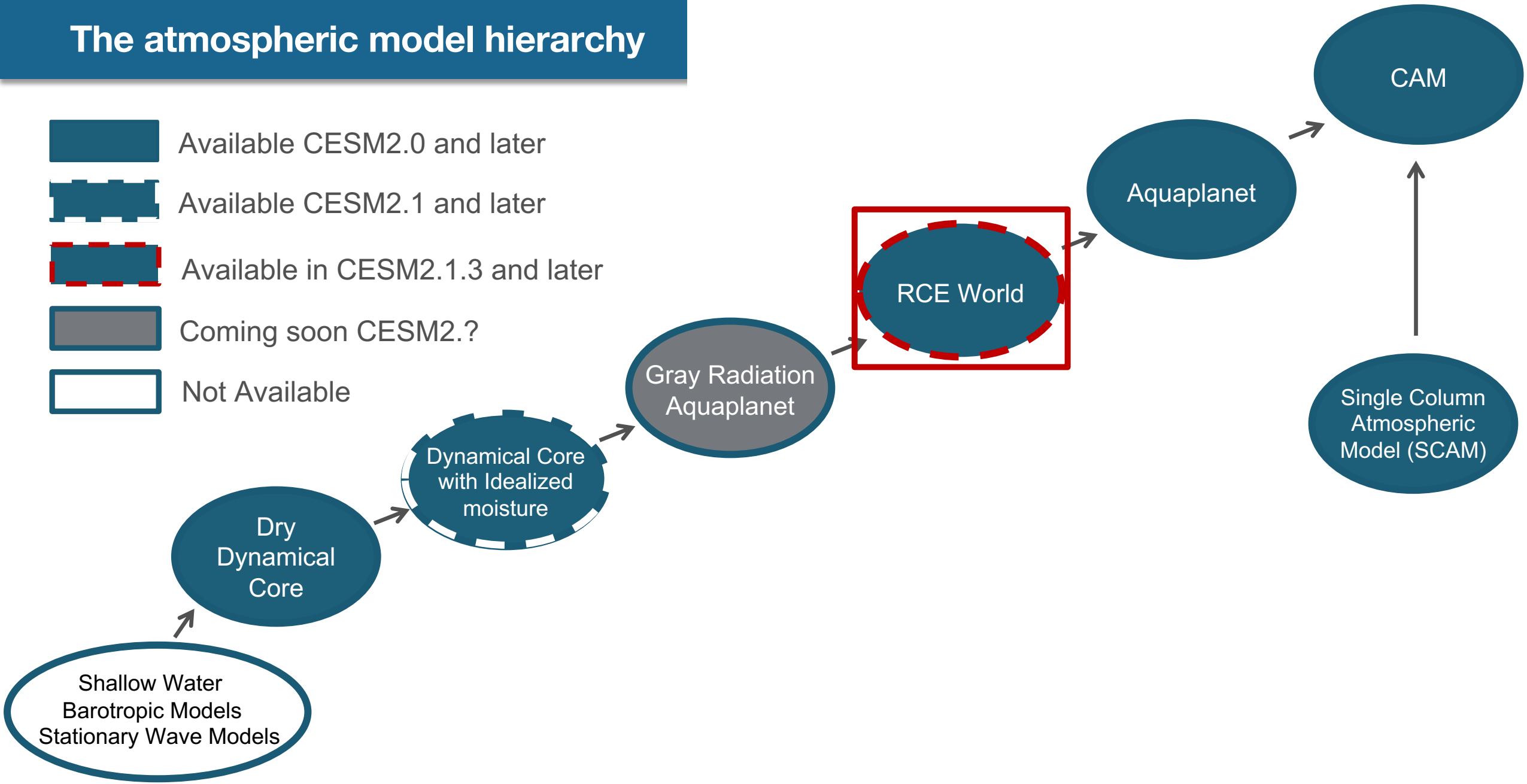
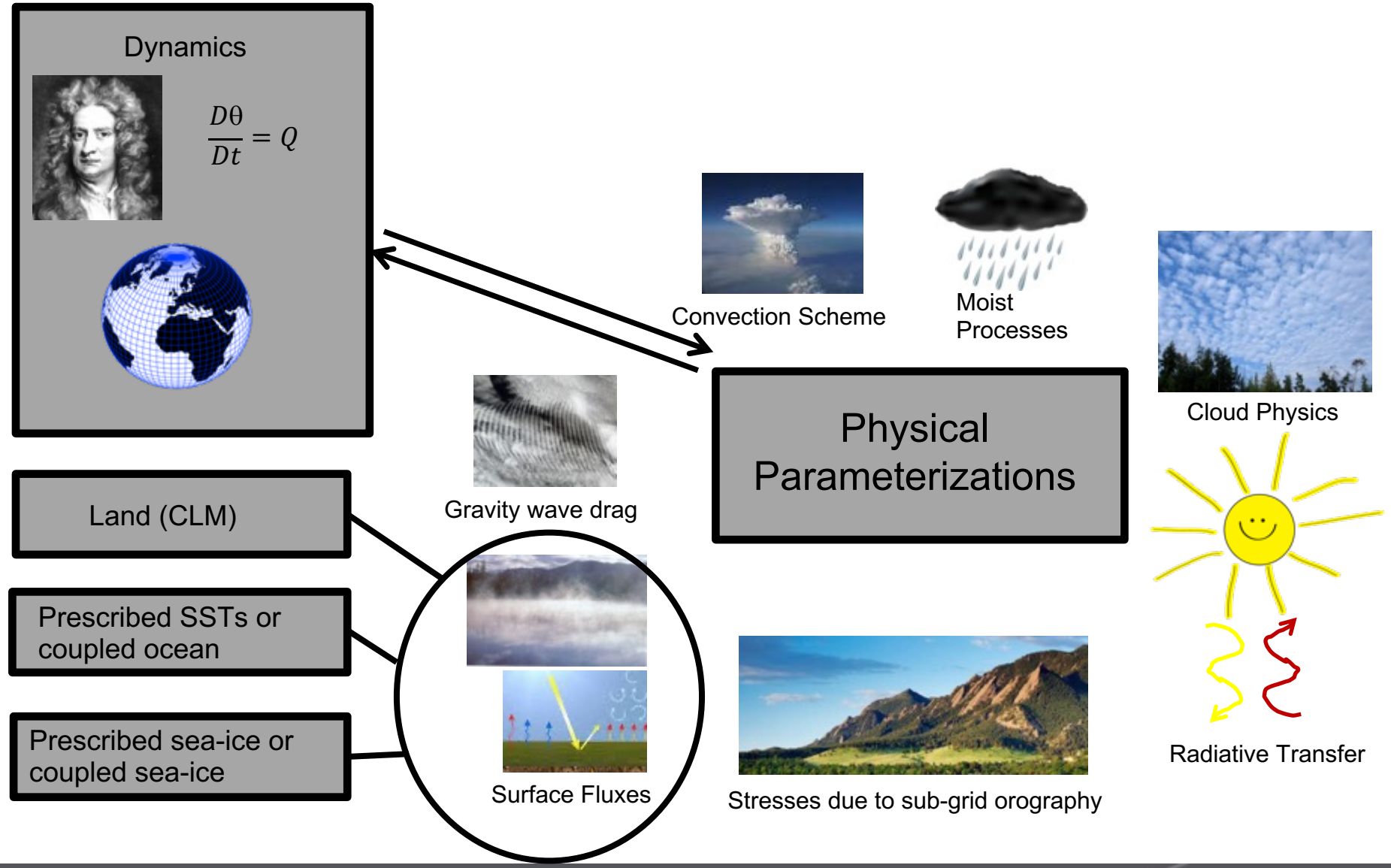


The atmospheric model hierarchy



Radiative Convective Equilibrium world (RCE-world)



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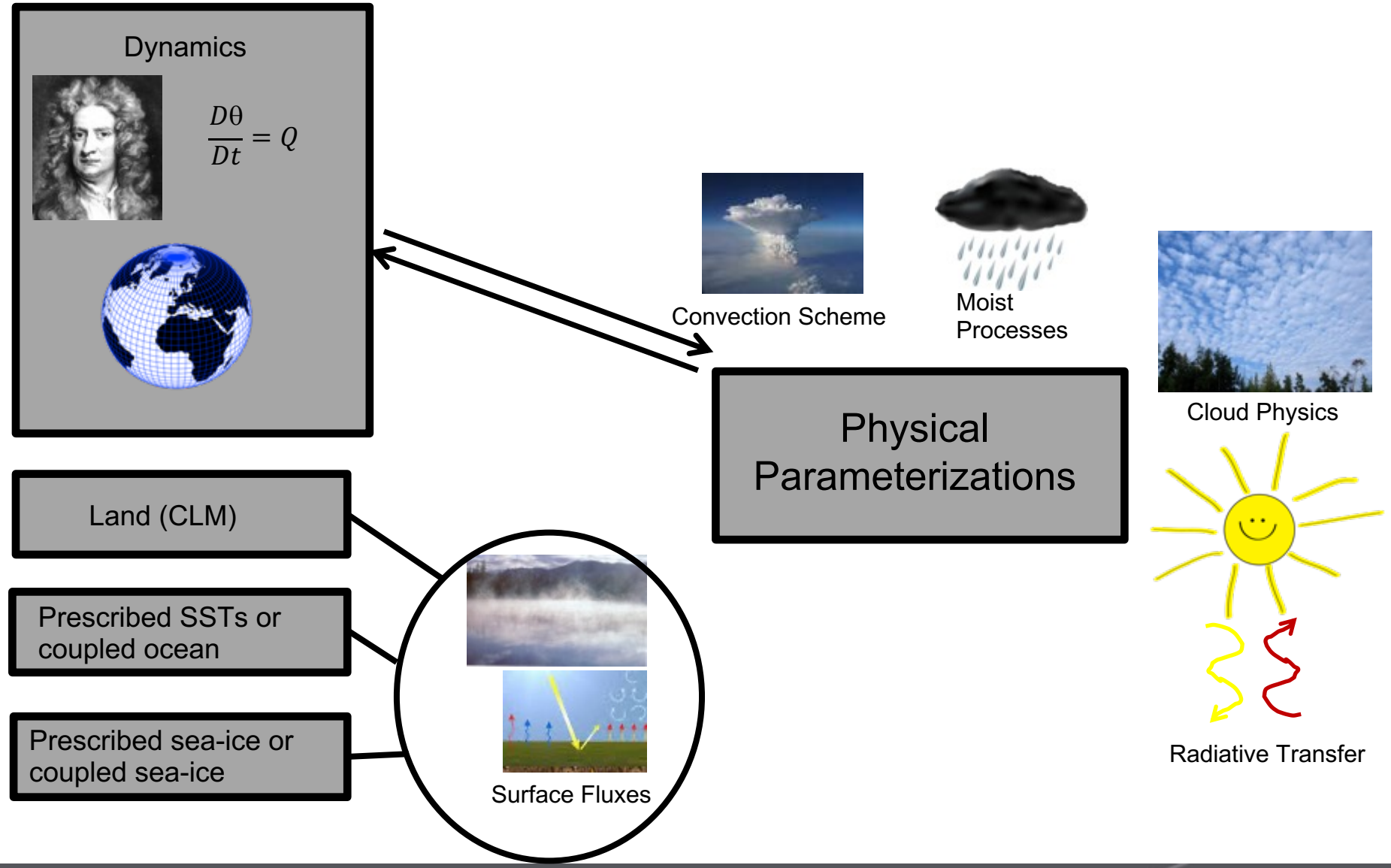

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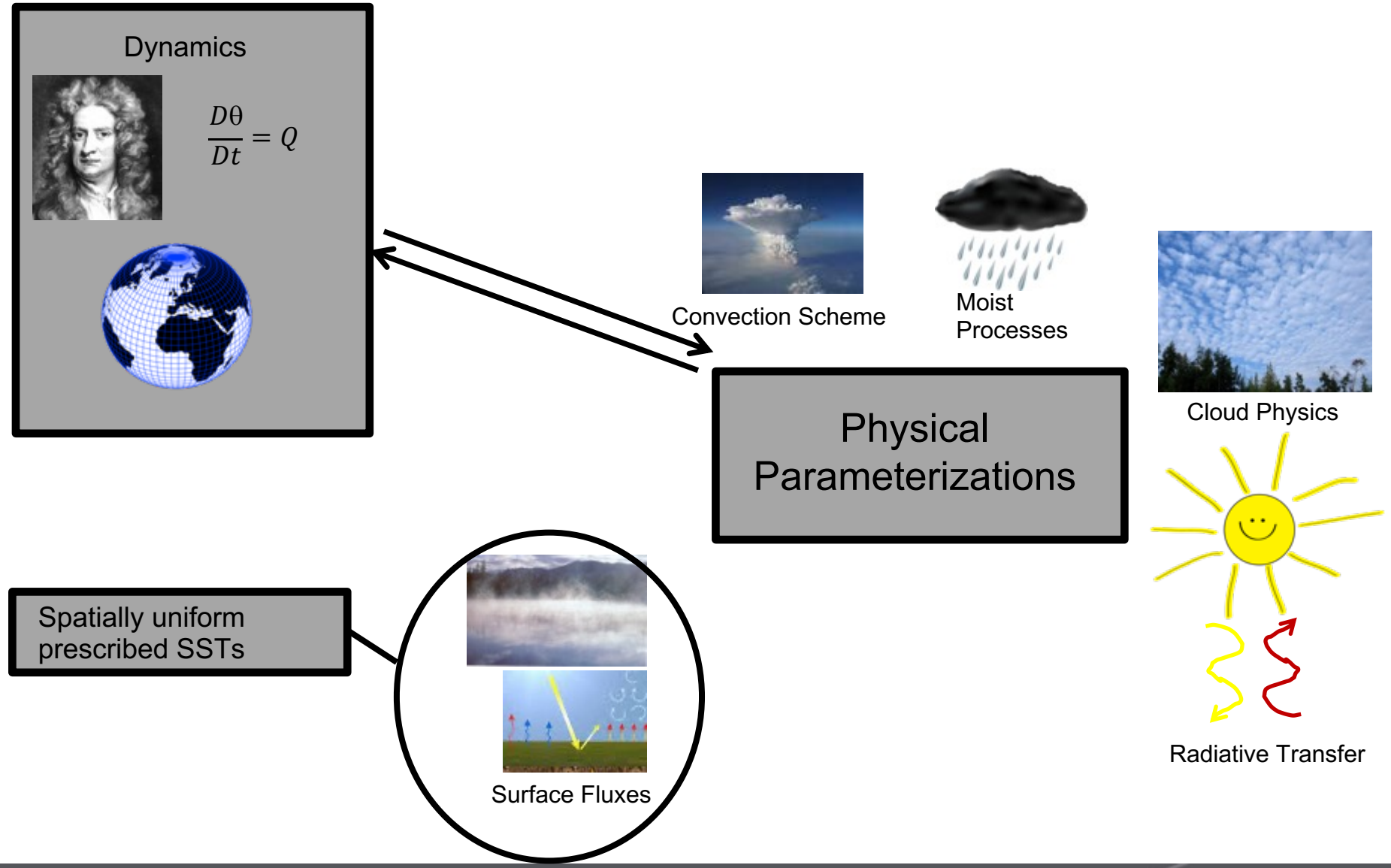

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Dynamics

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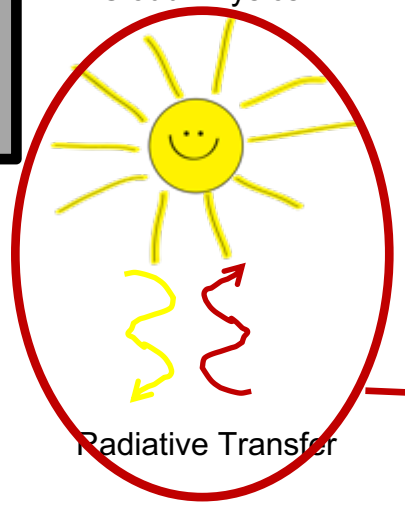
Convection Scheme

Moist Processes

Cloud Physics

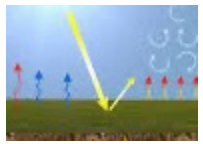
Physical Parameterizations



Radiative Transfer

No spatial gradients in insolation

Spatially uniform prescribed SSTs



Surface Fluxes

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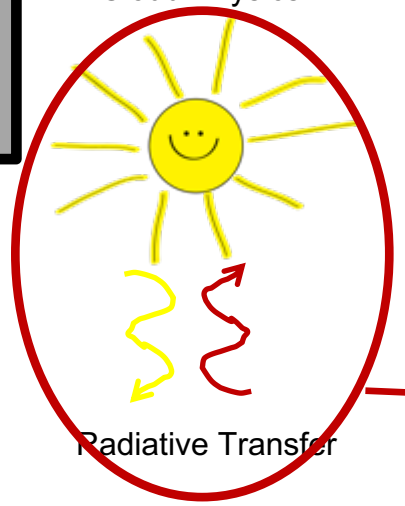

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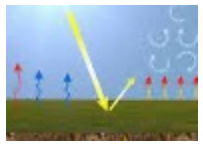

Surface Fluxes

Radiative Convective Equilibrium world (RCE-world)

Dynamics

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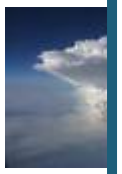
(Brian Medeiros, Kevin Reed)

- Following RCE-MIP protocols
- Useful for studying clouds, convection, climate sensitivity, convective aggregation



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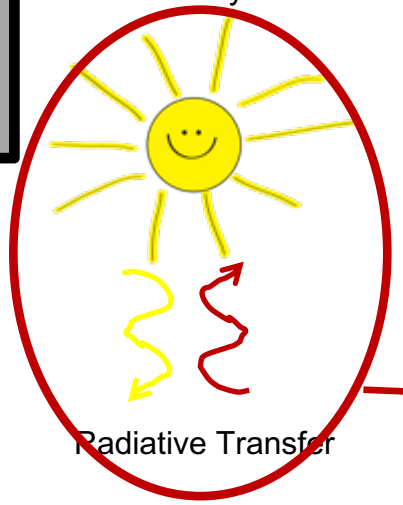

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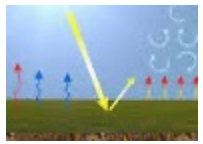

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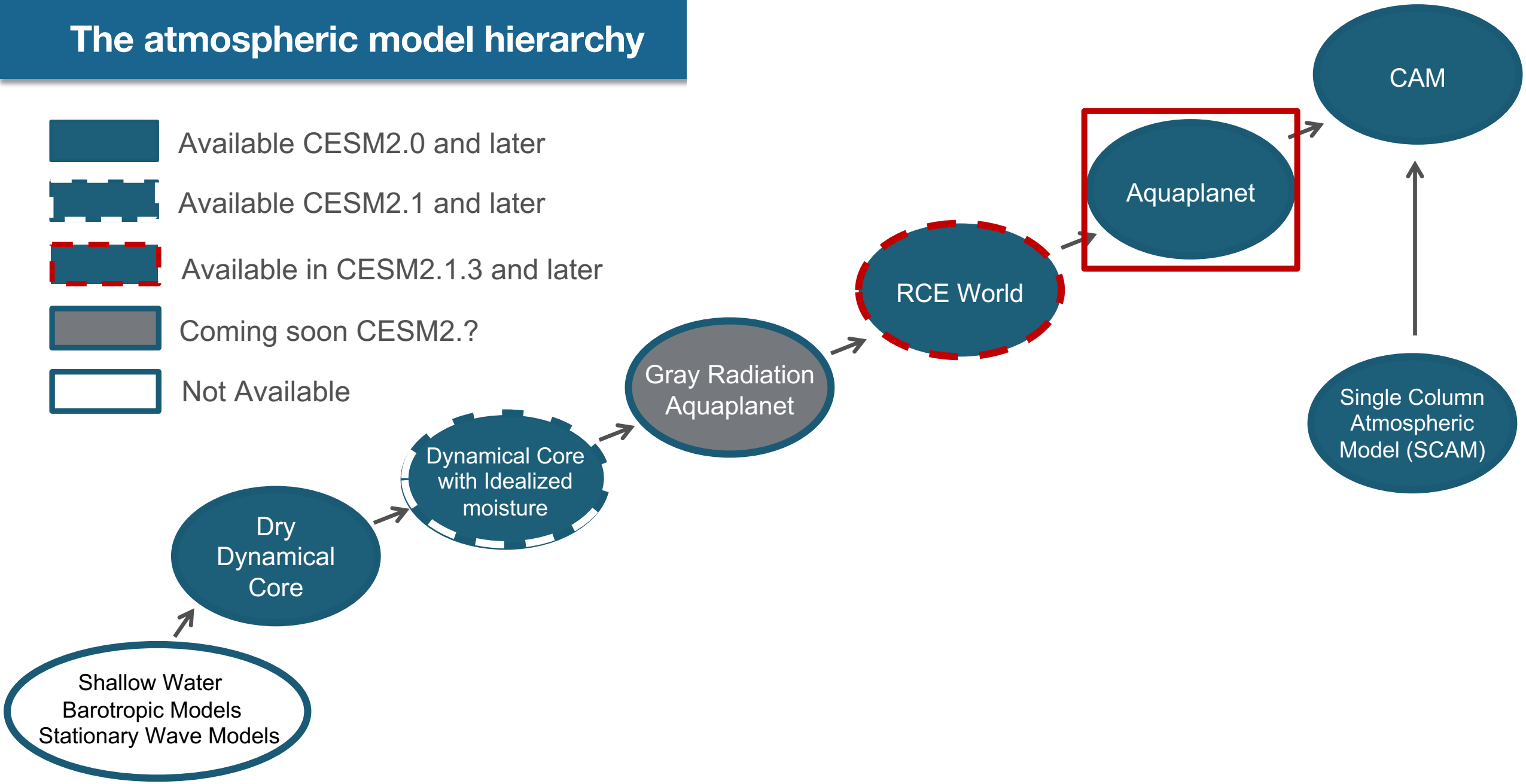

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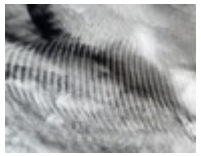
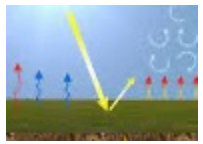


Gravity wave drag

Land (CLM)

Spatially uniform prescribed SSTs

Prescribed sea-ice or coupled sea-ice



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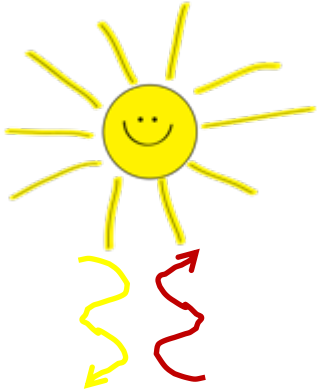

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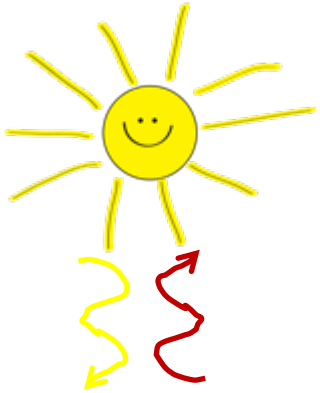
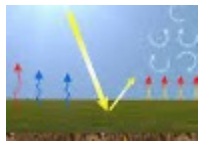


Radiative Transfer

Water-covered Earth

Prescribed SSTs or Slab Ocean



Surface Fluxes

The Aquaplanet

Dynamics

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

Convection Scheme

Moist Processes

Cloud Physics

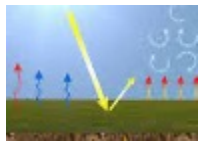
Physical Parameterizations

(Brian Medeiros, Jim Benedict, Dave Williamson Jerry Olson)

- Prescribed SST or slab ocean
- Easy switch between Aquaplanet Experiment SST profiles (Neale and Hoskins 2000) or user-specified SSTs.
- CAM4, CAM5 or CAM6 physics.

Water-covered Earth

Prescribed SSTs or Slab Ocean



Surface Fluxes

Next Steps

Planned implementation of SLIM (Simple Land Interface Model)

- An idealized bucket land model has been developed. (Lagüe, Bonan and Swann (2019))
- Bucket model with specified surface properties
- Code is not release ready.
- Should be engineered into a release branch in the fall.

Separating the Impact of Individual Land Surface Properties on the Terrestrial Surface Energy Budget in both the Coupled and Uncoupled Land–Atmosphere System

MARYSA M. LAGUË

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GORDON B. BONAN

National Center for Atmospheric Research, Boulder, Colorado

ABIGAIL L. S. SWANN

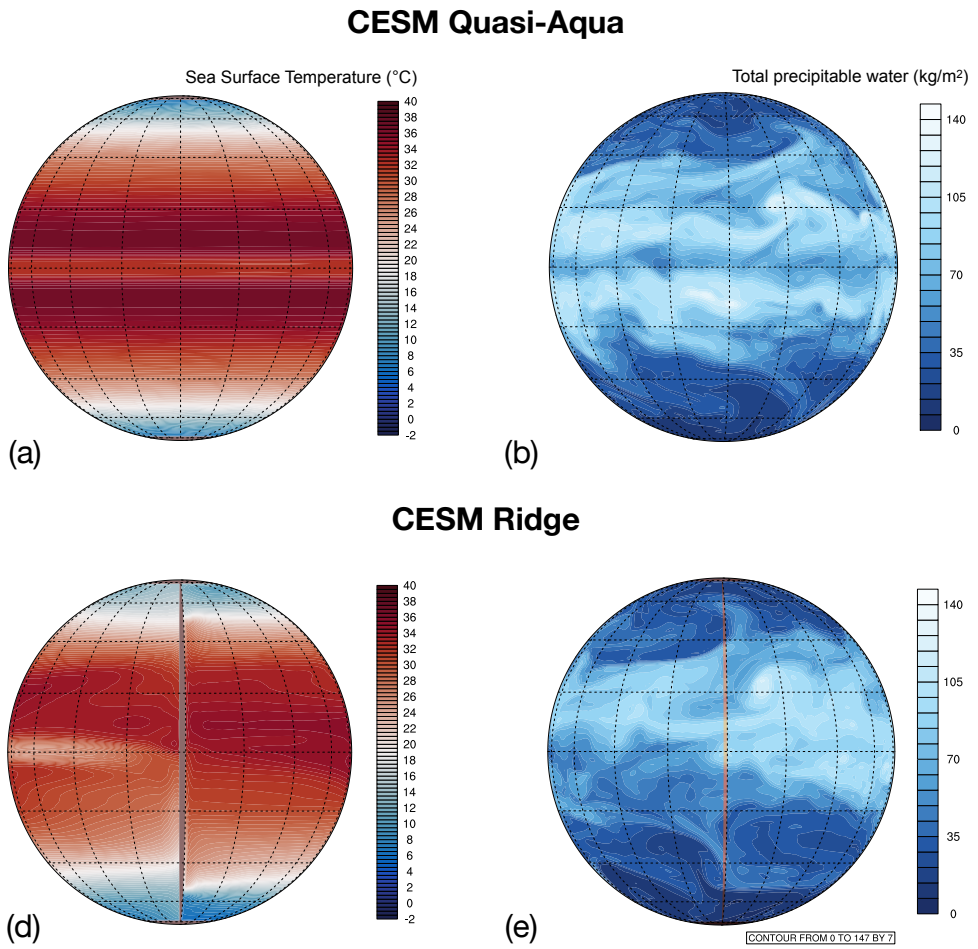
Department of Atmospheric Sciences, and Department of Biology, University of Washington, Seattle, Washington

Will be useful for idealized land-atmosphere coupling studies and will greatly simplify the set-up of idealized coupled atmosphere-ocean configurations.

Ongoing coupled aquaplanet efforts

(Xiaoning Wu, Scott Bachman, Frank Bryan, Gustavo Marques, Kevin Reed, Christopher Wolfe)

- CAM4 atmosphere (~1 deg)
- MOM6 ocean (~2 deg), 4000m depth, symmetric bottom topography
- CICE sea ice
- CLM5 land
- Initialization using an idealized ocean climatology from Pedro Di Nezio

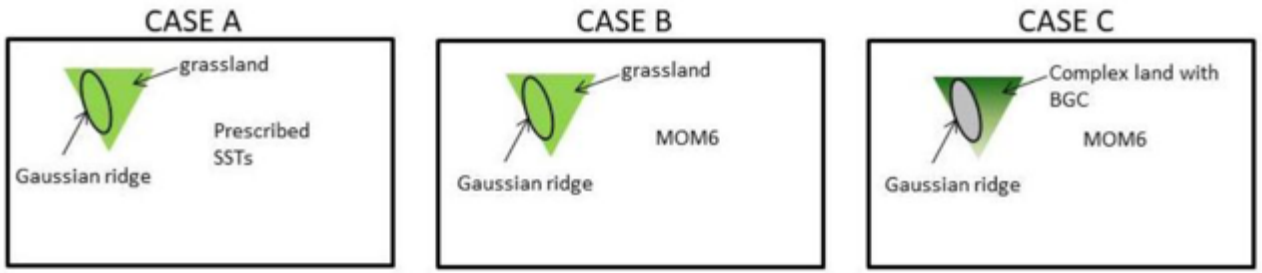


A plan to bring this all together

Development of infrastructure to simplify coupled modelling

Cyberinfrastructure for streamlining coupled, simplified climate modelling within the Community Earth System Model, NSF CSSI (PI's: Scott Bachman, Isla Simpson, Mariana Vertenstein, Gokhan Danabasoglu).

Typically, users don't want to run an out-of-the-box idealized configuration..



We will:

(1) Develop a Simpler Models query tool to allow users to easily understand which simpler model configurations are available and supported, their compatibilities, different options (e.g., physics packages)

(2) Develop infrastructure for customization of ocean basin and land geometries (overlaps with needs of the Paleoclimate community)

(3) Provide a toolchain for seamless model setup (components, grids, domain, physics) among the simpler-model hierarchies.

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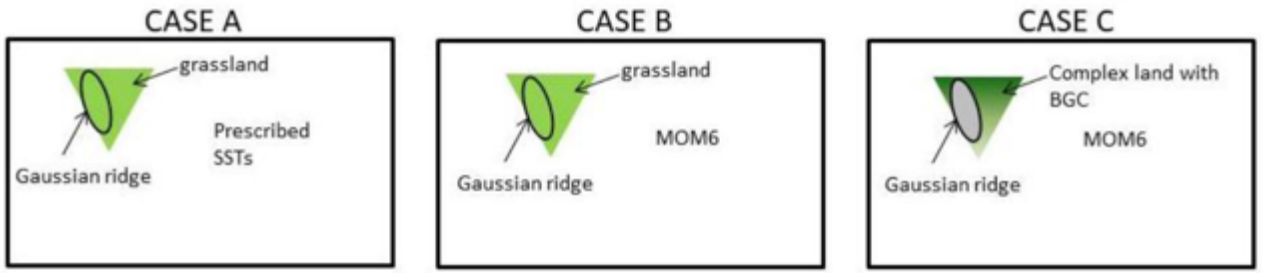

Experiment idea

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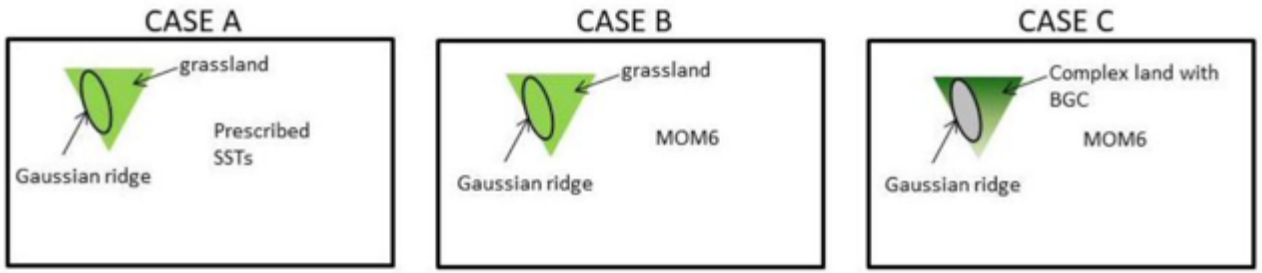

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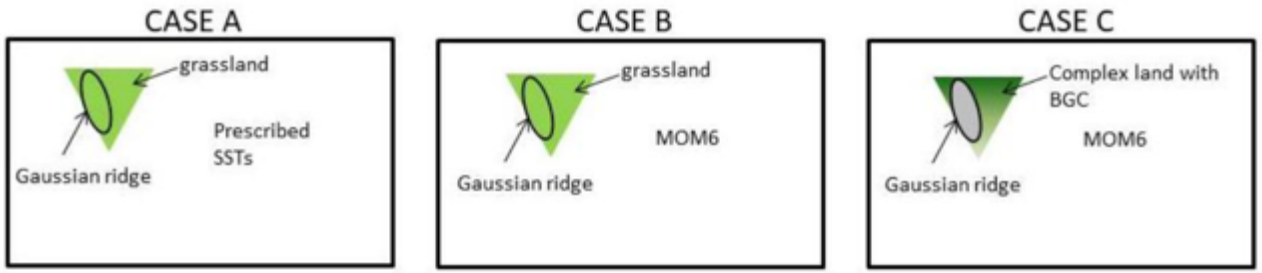

Experiment idea

Toolkits and information needed to develop desired configuration

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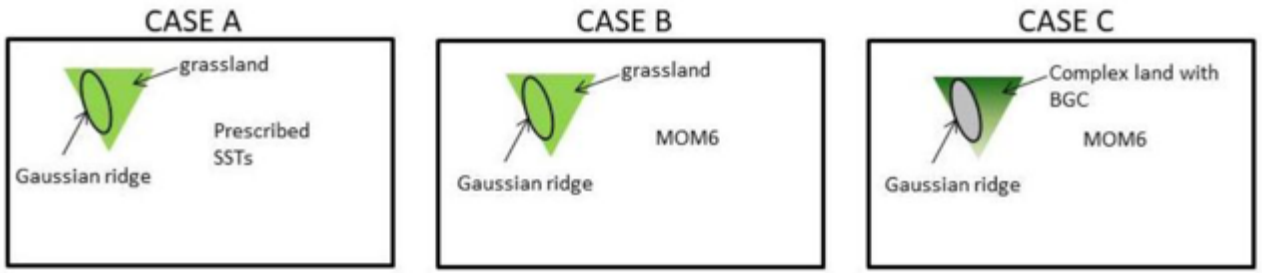

Experiment idea

Toolkits and information needed to develop desired configuration

Step-by-step guidance for seamless model set-up

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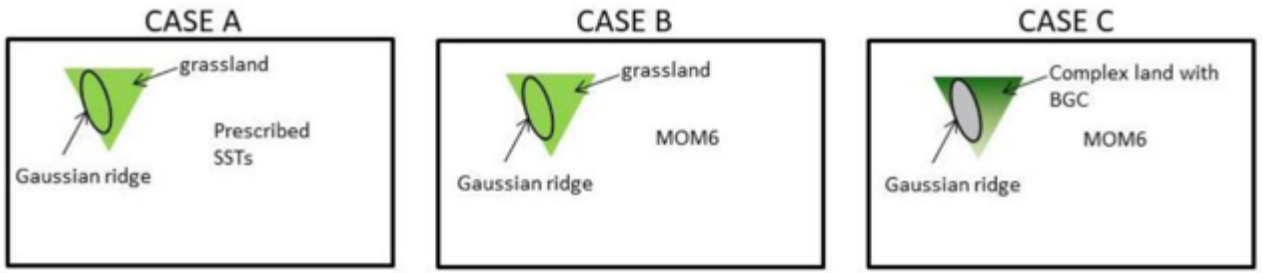

Experiment idea

Toolkits and information needed to develop desired configuration

Step-by-step guidance for seamless model set-up

A working, coupled, idealized configuration

Conclusions

- The atmospheric model hierarchy available within CESM has expanded considerably since 2014
- Next steps are to extend our capabilities in coupled idealized modelling and customization took kits, inc. cubed sphere grid topology (w/ A. Adcroft), ocean bathymetry tool (Altuntas).
- At present, coupled idealized modelling doesn't really have a home. ISCA (University of Exeter) is a modelling framework that is widely used for idealized atmosphere modelling. MIT GCM is a modeling framework that is widely used for idealized ocean modelling.
- Resources are limited, particularly software engineering resources and these resources are used for both the comprehensive CESM and idealized models. (So far this effort has been funded by some supplemental funding from NSF Climate and Large Scale Dynamics and base funds to NCAR. Now, we are able to expand our coupled capabilities and implement SLIM with additional NSF funding)
- We hope to see continued and increased use of the idealized configurations within CESM to ensure their continued support.
- Please get in touch if your interested in being a guinea pig for testing the new coupled model toolkits as they become available (bachman@ucar.edu, islas@ucar.edu)