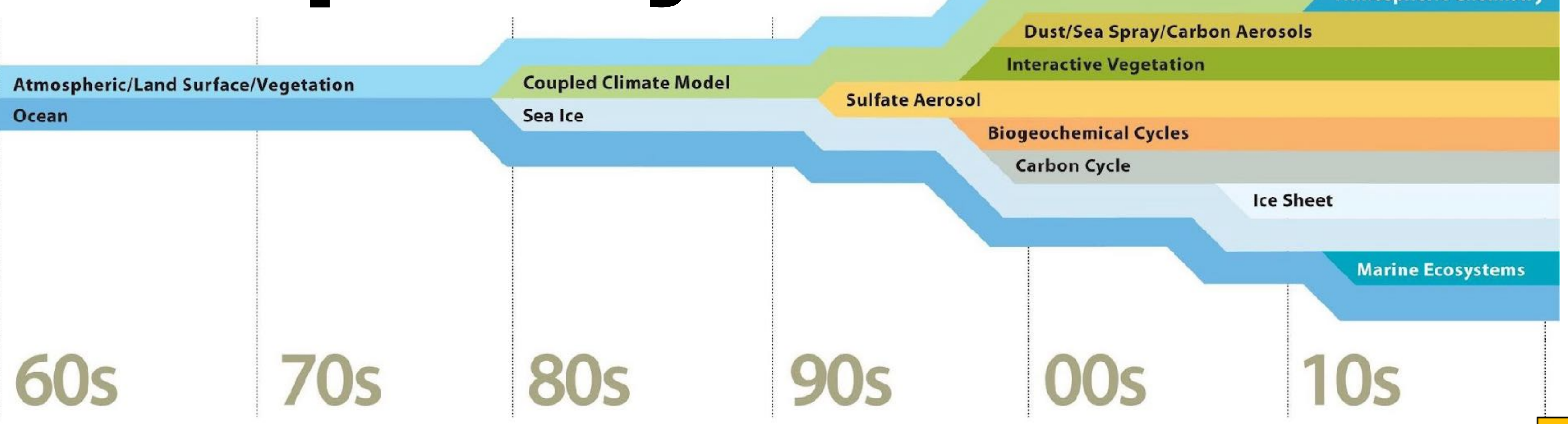
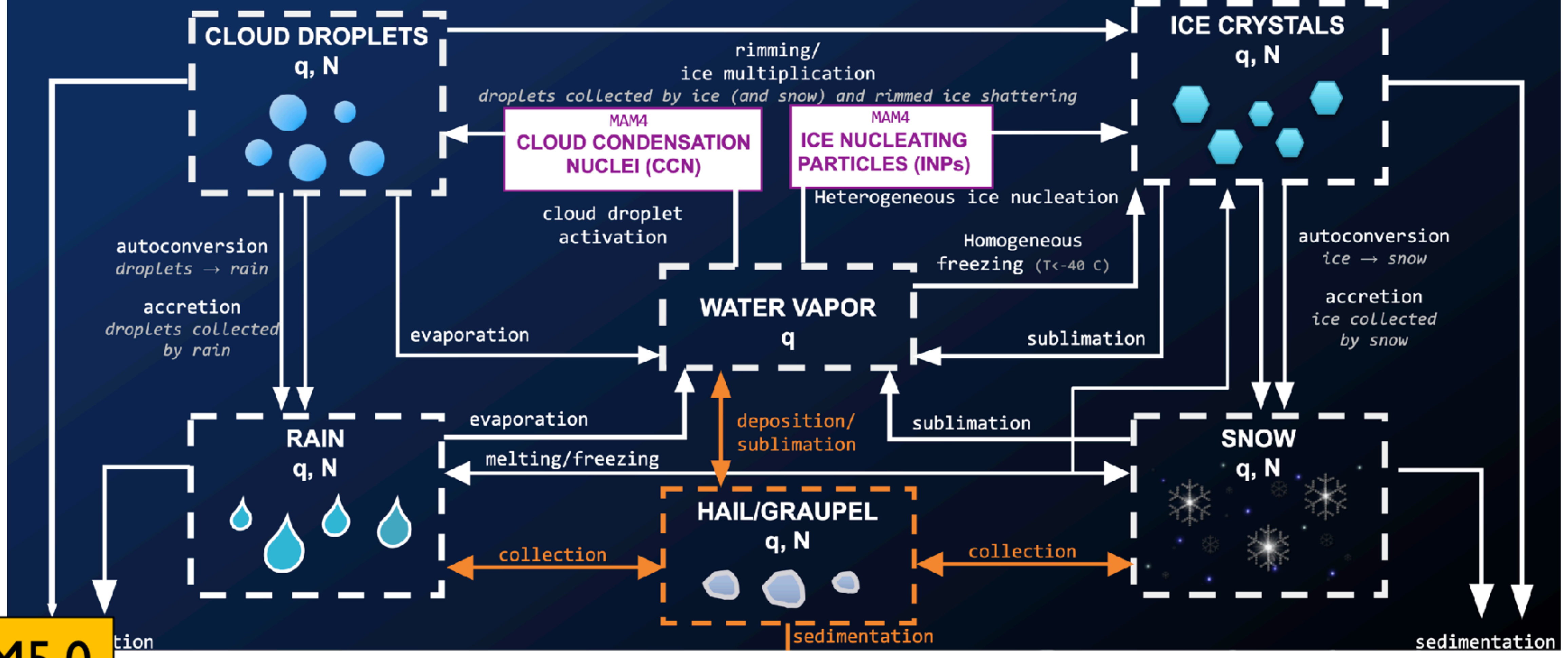
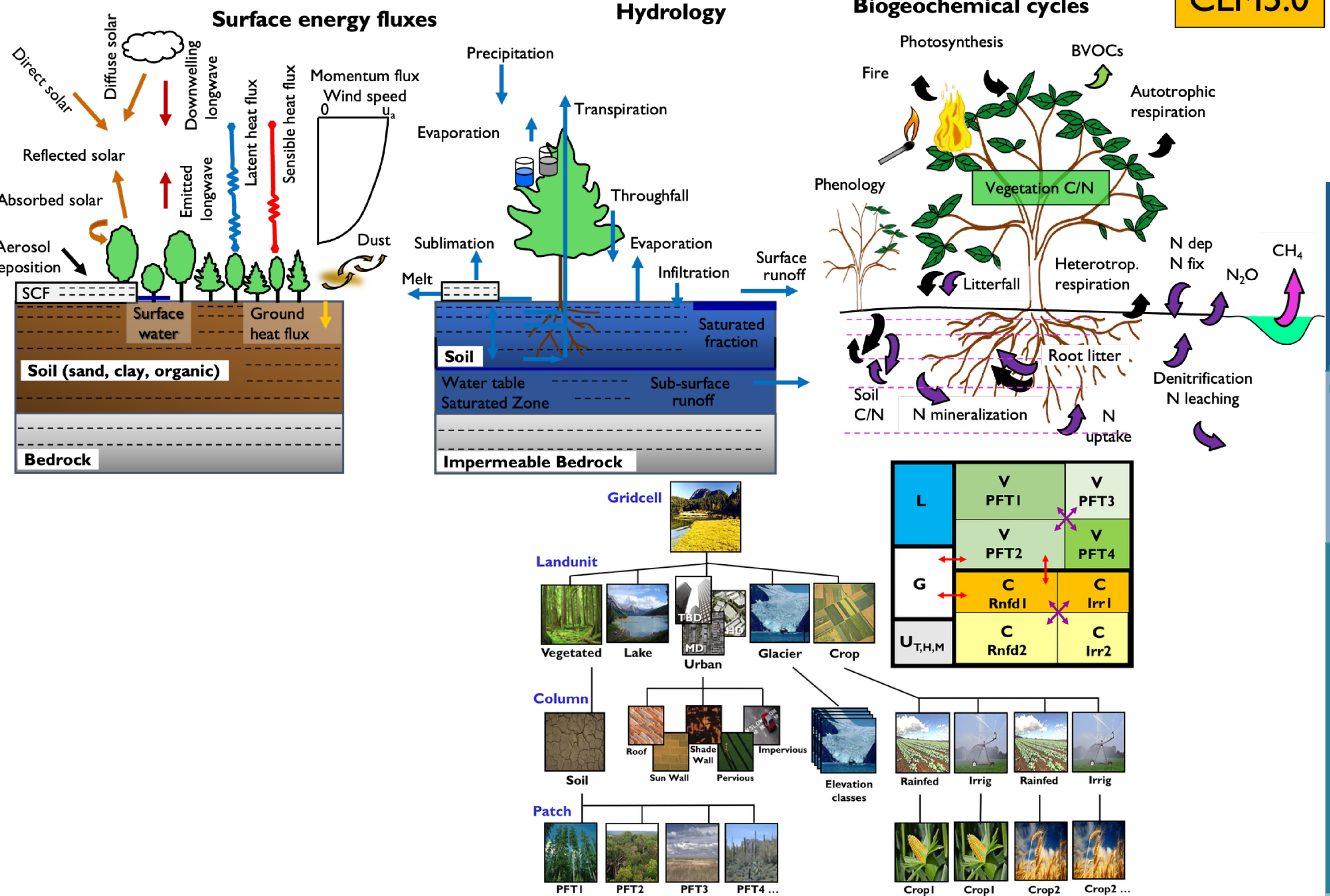
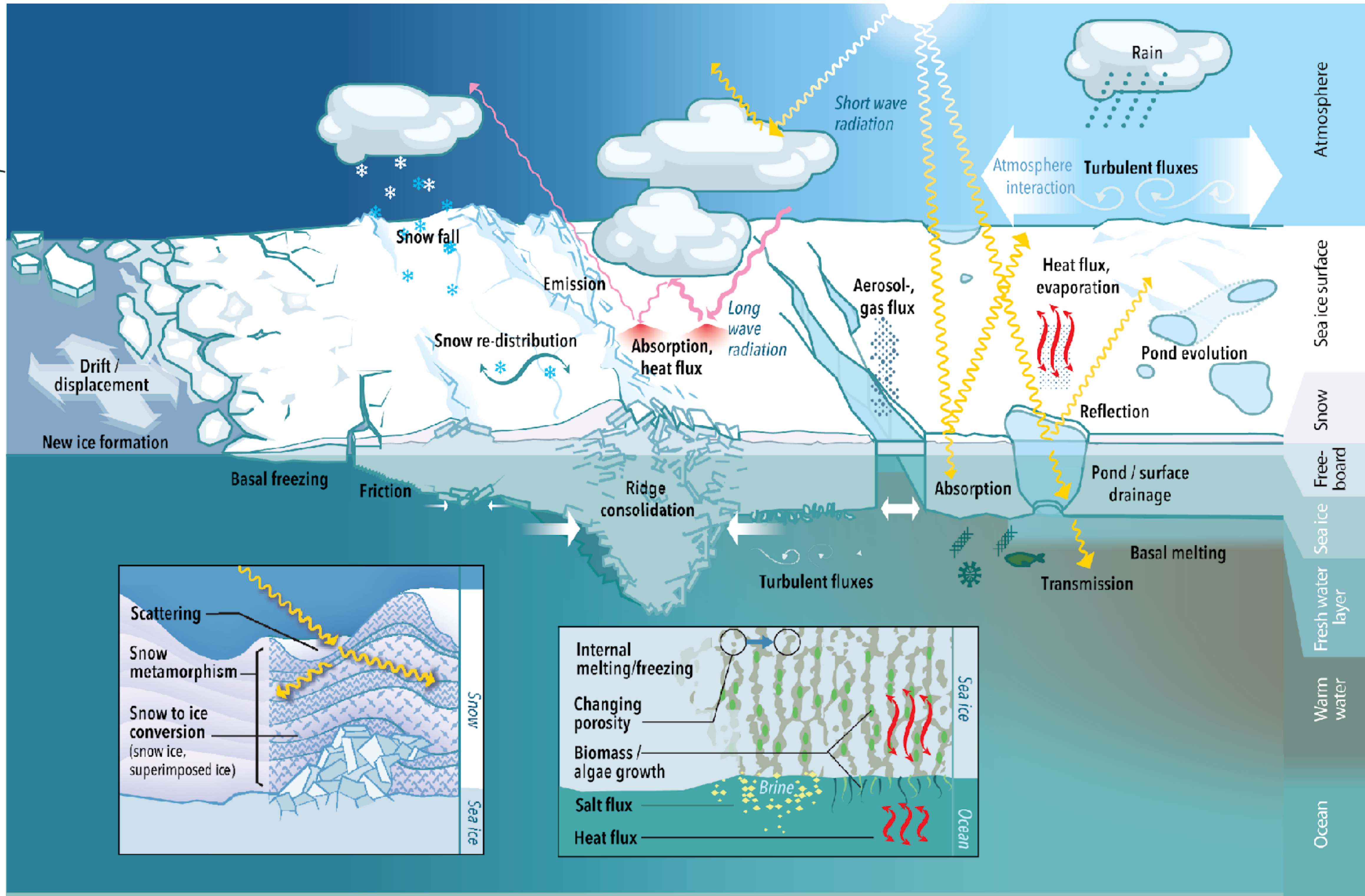
Complexity





CLM5.0





Simpler Models

in CESM

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, Mariana Vertenstein, Colin Zarzycki

Brian Medeiros & Isla Simpson, CESM Tutorial 2025

spherical cow

Challenges in understanding model solutions

- CESM is complicated. Everything is changing all at once
- The system is typically in a quasi-equilibrium/balanced state obeying its conservation constraints (Energy, Momentum, Moisture)
- 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.
- It requires a lot of computation to solve the system because of the complexity.

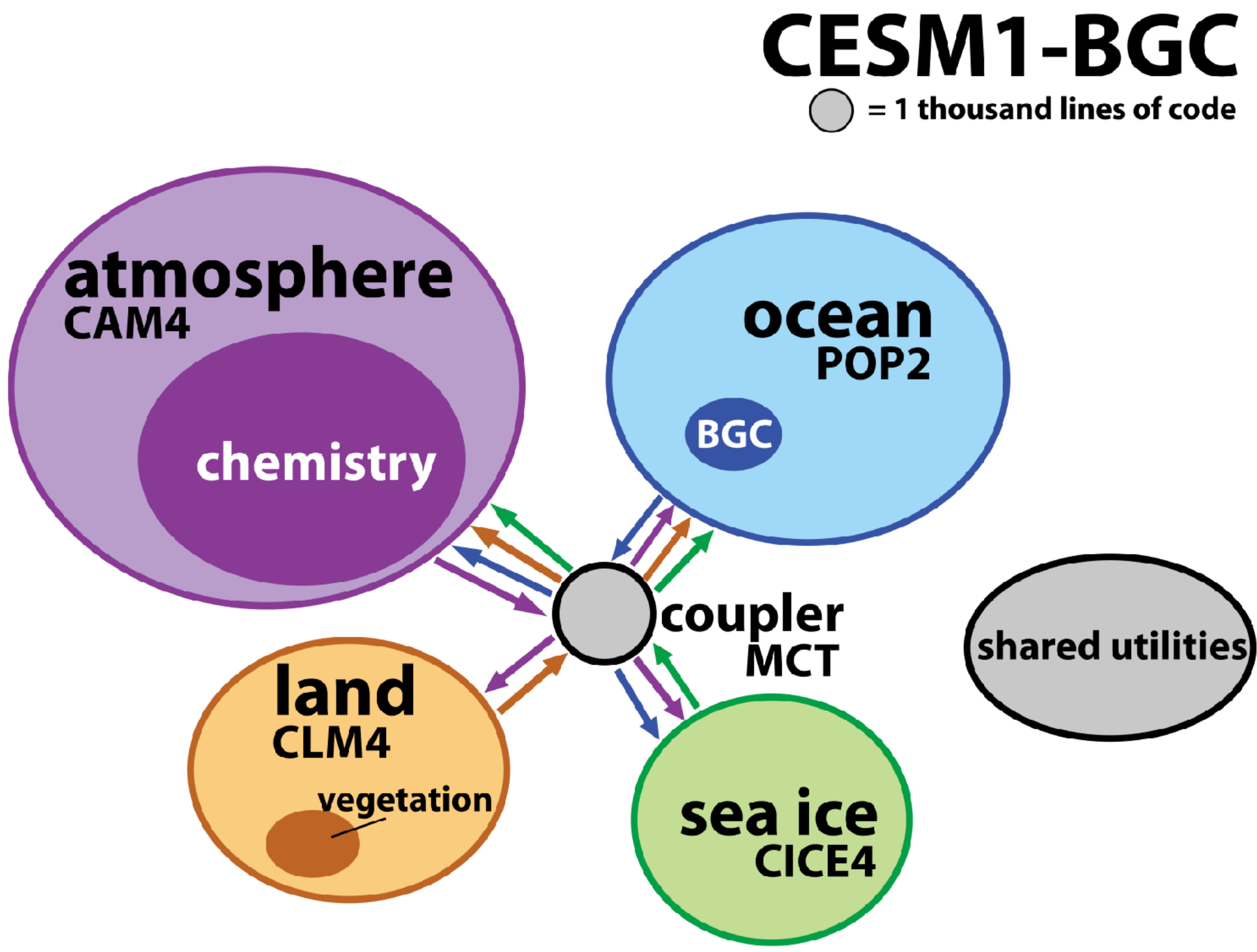
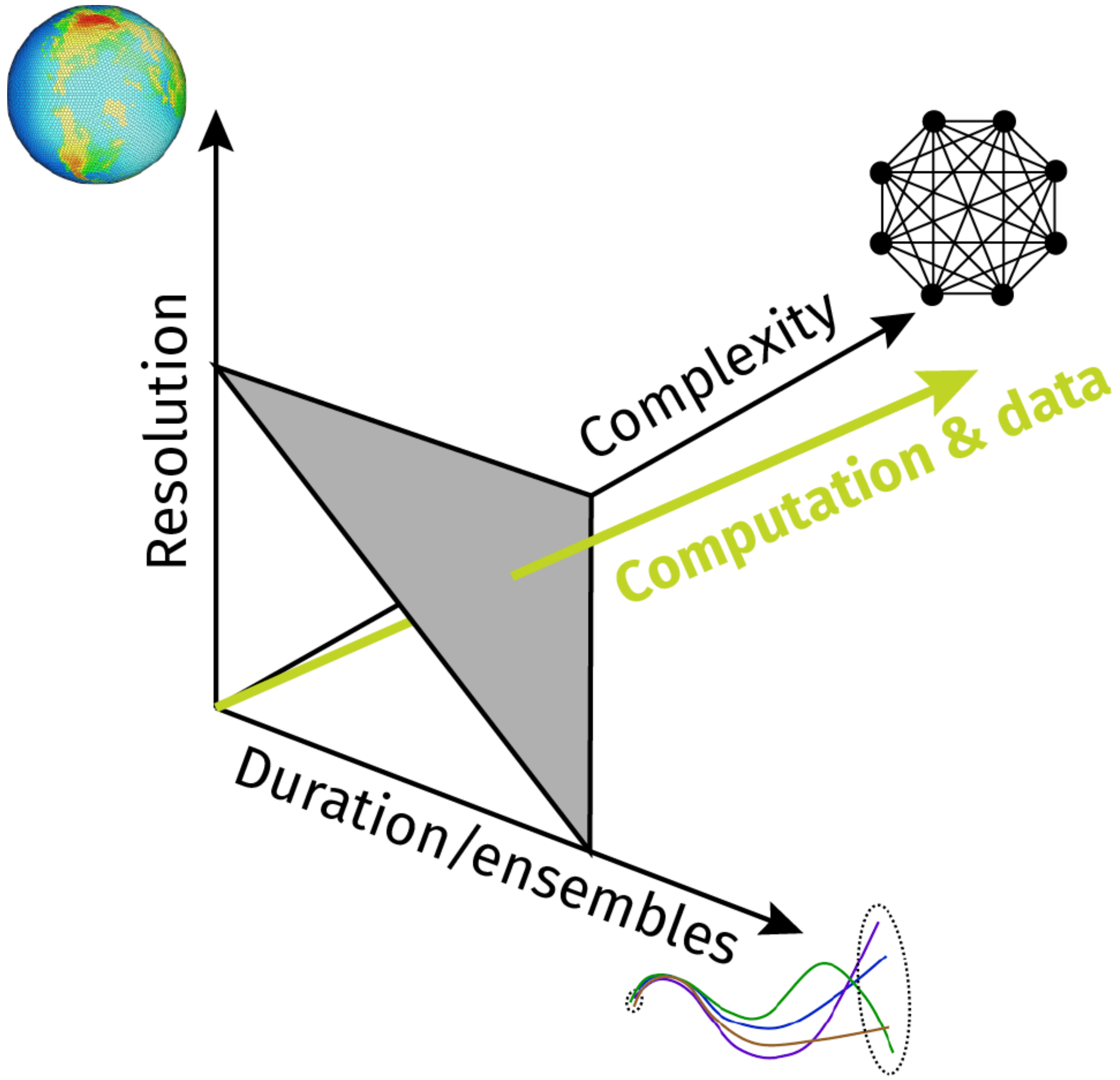


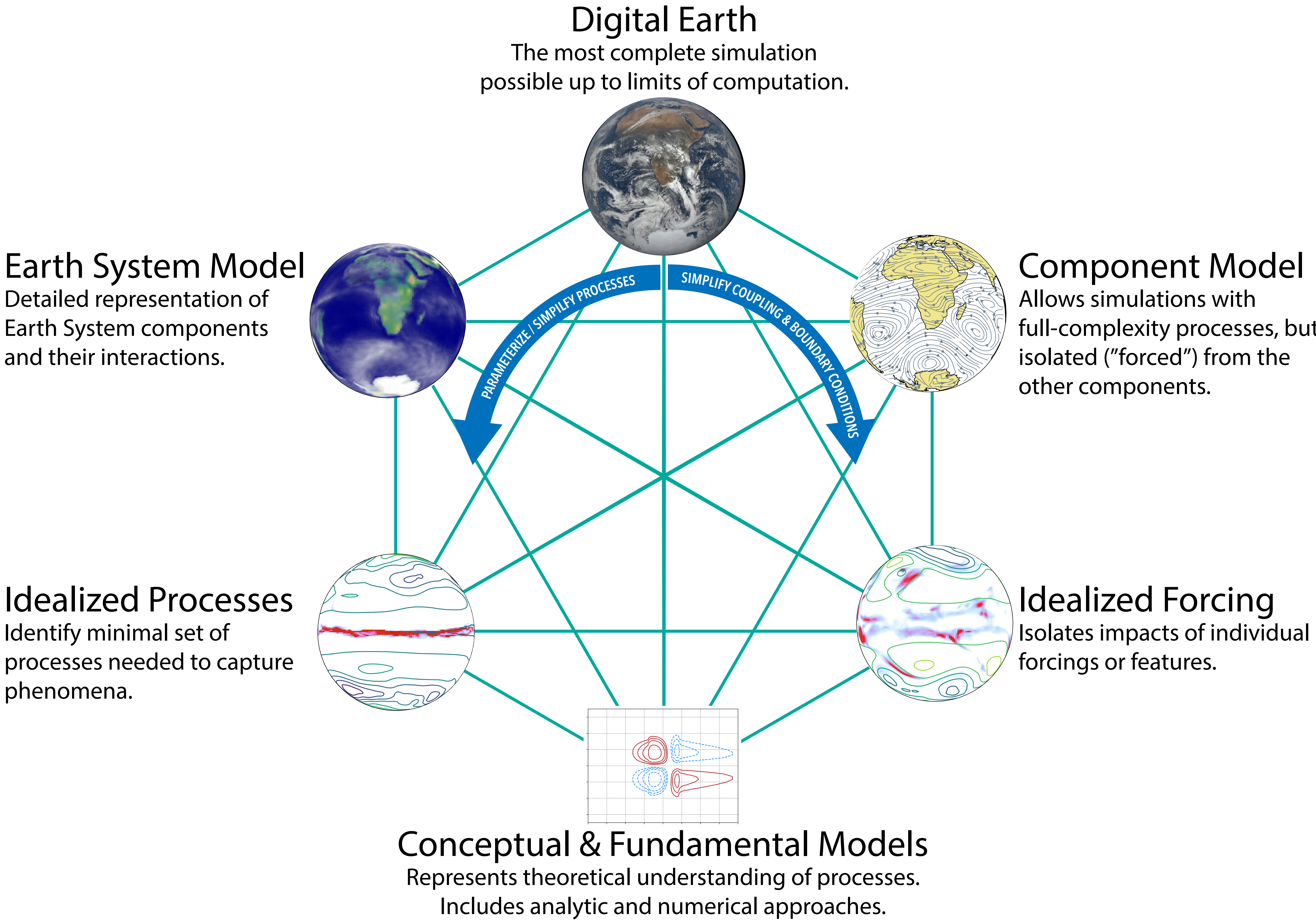
Figure 1. Architecture diagram for CESM1-BGC.

Alexander & Easterbrook 2015

How can we pull it all apart and understand it?

- Detailed diagnosis of model output
- Performing idealized experiments with the comprehensive version of CESM
- Using simplified versions of CESM (and run experiments)
  - The capacity to run idealized models within CESM is growing
  - Simpler models website: https://www.cesm.ucar.edu/models/simple
  - TODAY: tour of configurations with some examples





Reed et al. 2025

Simpler models

versions of CESM that only contain certain components and/or idealized representation of certain components

PRO	CON
Easy to perturb	Less realistic; harder to compare with observations
Allow for idealized experiments to identify causal pathways	
Cheap	
Allows for parameter sweeps to identify sensitivities	

The atmosphere model hierarchy

www.cesm.ucar.edu/models/simple

Slide modified from Isla Simpson

The atmosphere model hierarchy

Dry Dynamical Core

- Dry Dynamical Core with Held-Suarez “physics”
  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)

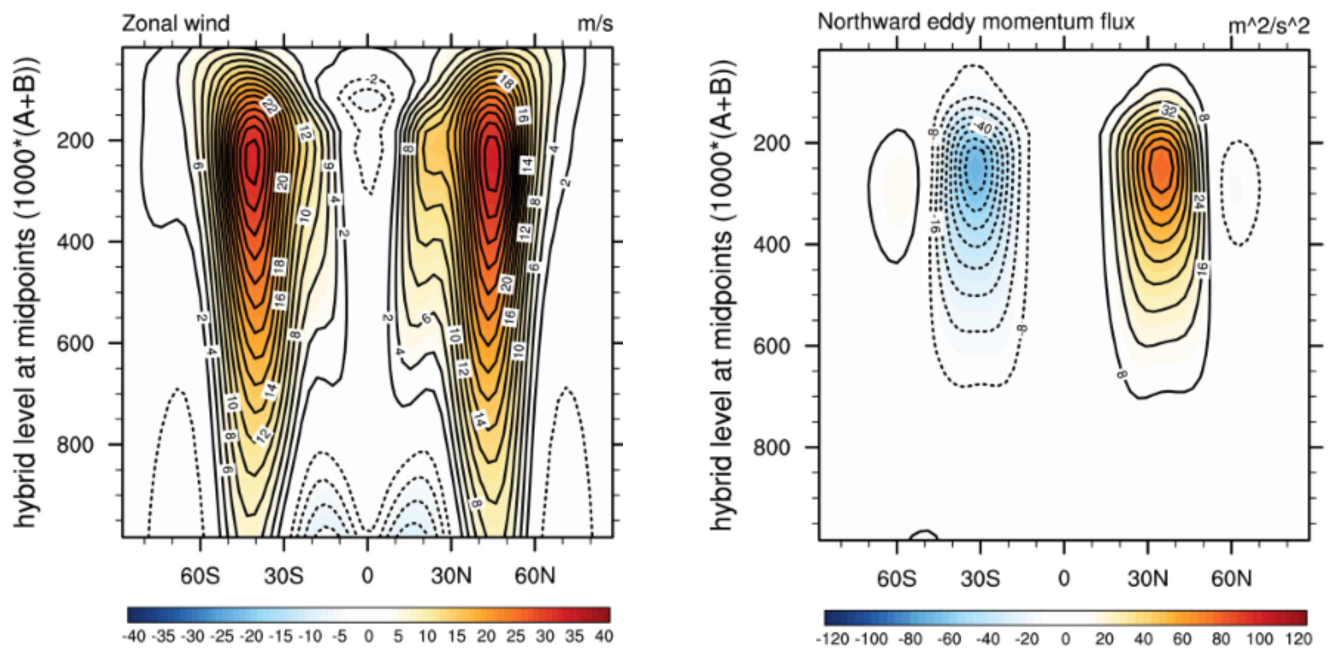
- ***Good for*** dry dynamics. Can easily perturb the temperature

- Compset: “FHS94”

- *Even simpler* →“FADIAB” compset
  (no forcing, as in DCMIP)

$$\frac{\partial v}{\partial t} = \ldots - k_v(\sigma)v$$

$$\frac{\partial T}{\partial t} = \ldots - k_T(\phi,\sigma)\left[T - T_{\mathrm{eq}}(\phi,p)\right]$$

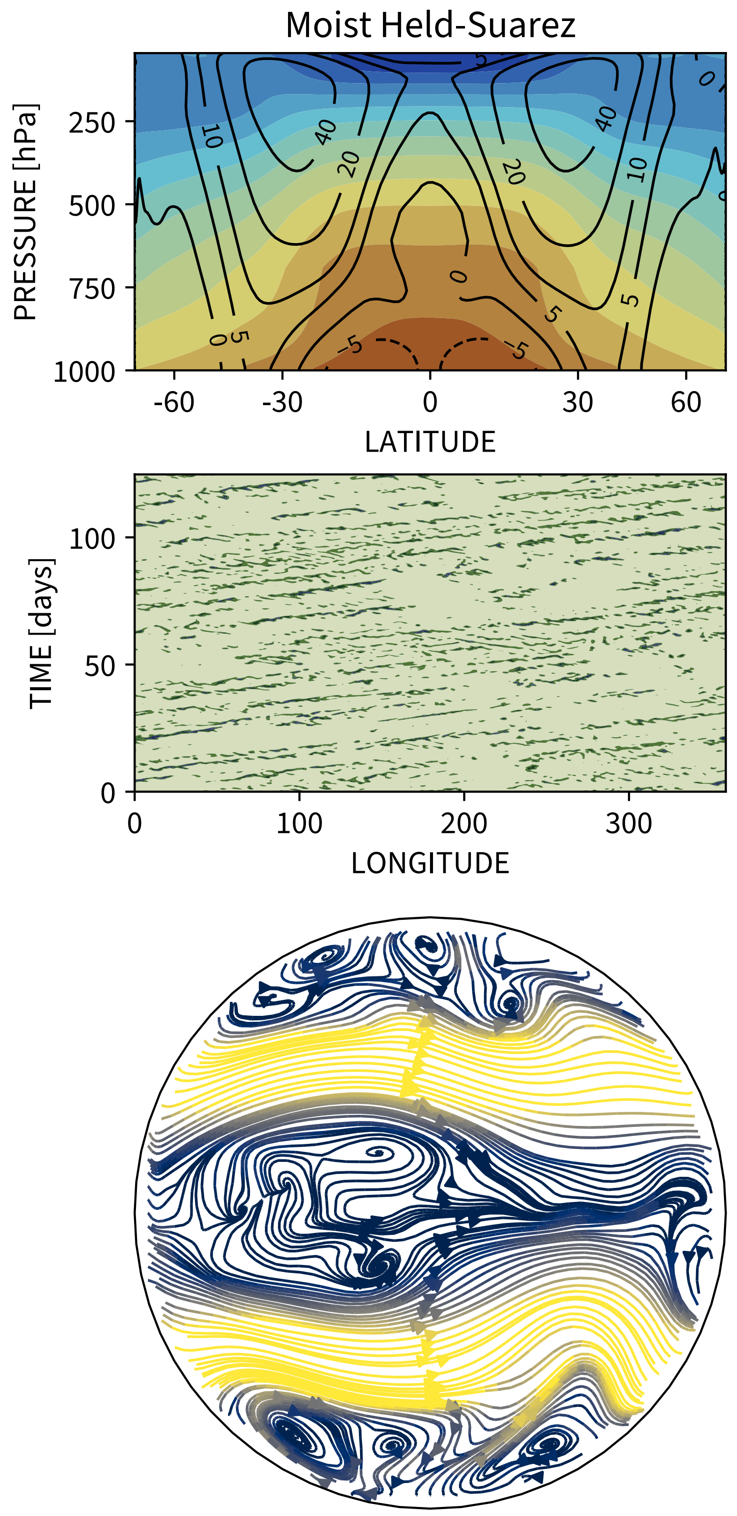


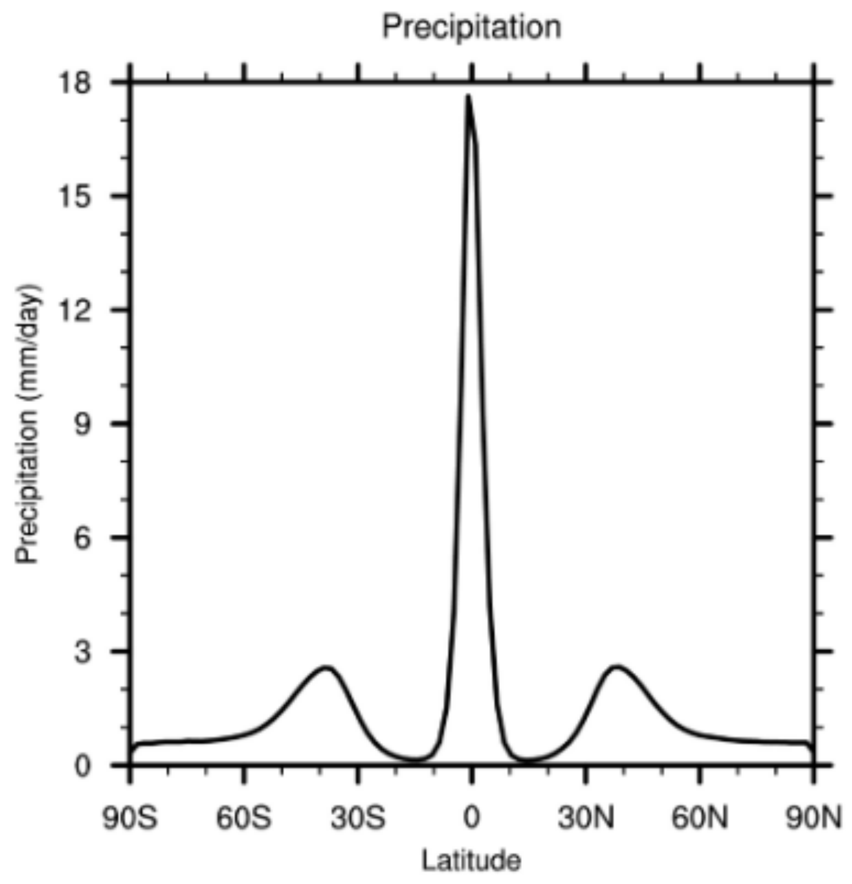
The atmosphere model hierarchy

HS94 with idealized moisture

$$\frac{\partial q}{\partial t} = -\frac{1}{\Delta t}\left(\frac{q - q_{\text{sat}}}{1 + \frac{L^2 q_{\text{sat}}}{c_p R_v T^2}}\right)$$

- 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. Surface sensible and latent heat flux using bulk formulae.
- Newtonian relaxation of the temperature field.
- Moisture is advected, condenses at saturation and immediately precipitated with an associated diabatic heating.
- ***Good for*** dynamical studies involving the interaction between moisture and the large scale flow.
- Compset: “FTJ16”

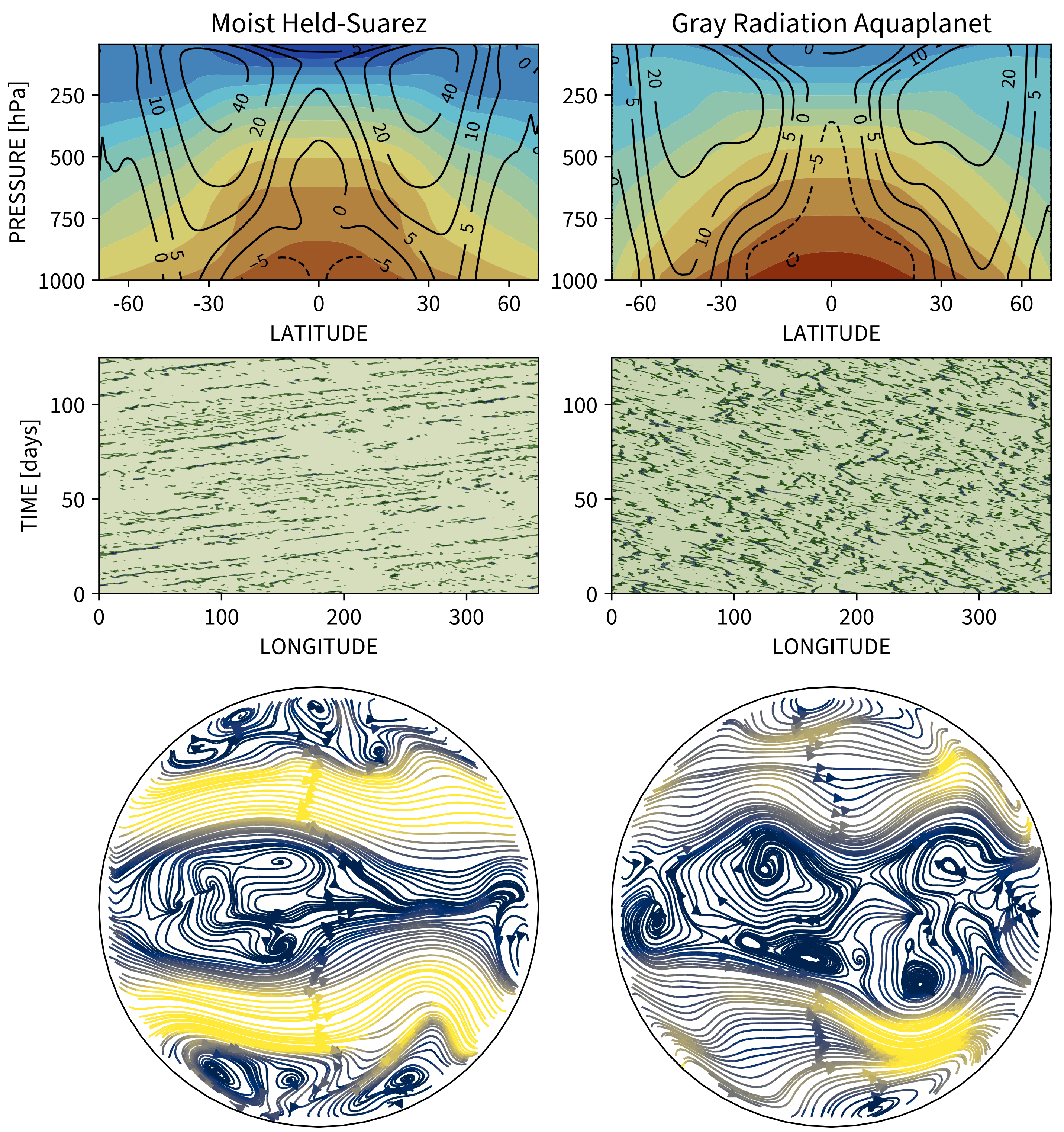




The atmosphere model hierarchy

Gray radiation aquaplanet

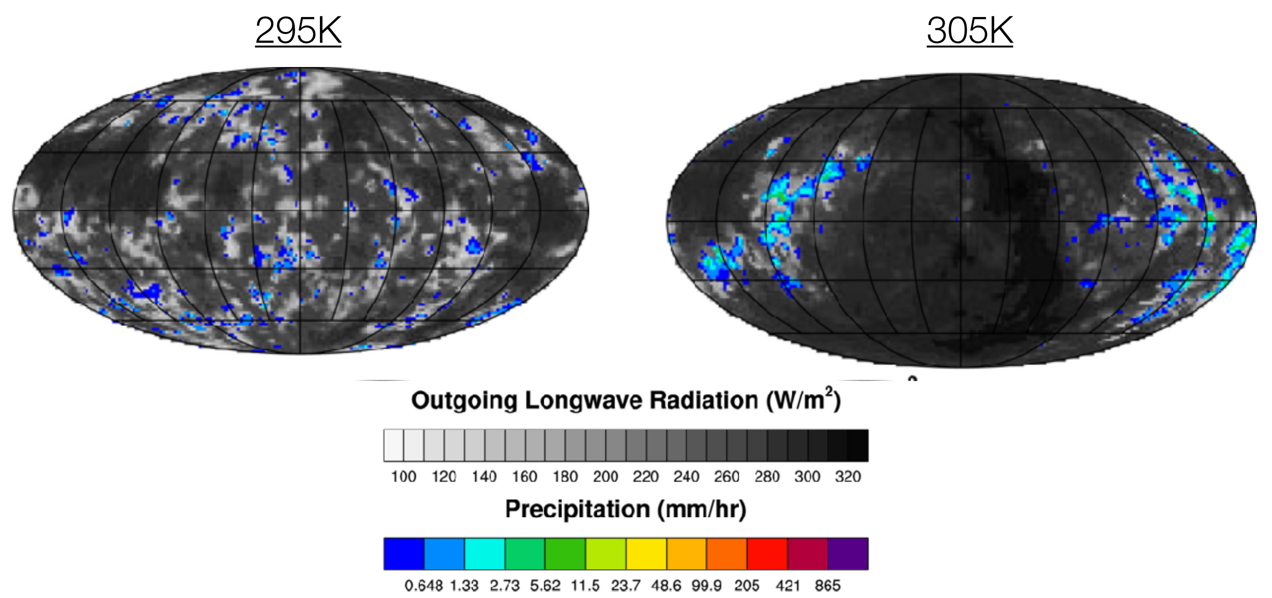
- Follows Frierson et al. 2006
- Slab Ocean
- Gray radiative transfer with specified longwave absorber.
  Radiation doesn't see water vapor;
  Shortwave only at surface
- No clouds
- Bulk formulae for surface drag, sensible, and latent heat fluxes.
- ***Good for*** idealized studies of the interactions between the circulation and radiation and moisture
- Compset “FGRAYRAD”



The atmosphere model hierarchy

Radiative-Convective Equilibrium

- Radiative Convective Equilibrium (RCE) world
  https://www.cesm.ucar.edu/models/simple/rce
- Compatible with the RCEMIP protocol
  (Wing et al. 2018, 2020)
- No rotation, uniform and constant insolation
- Uniform prescribed SSTs
- Planetary rotation and solar zenith angle can be specified.
- ***Good for*** convective organization, comparison with CRMs, etc.
- Compset: “QPRCEMIP”

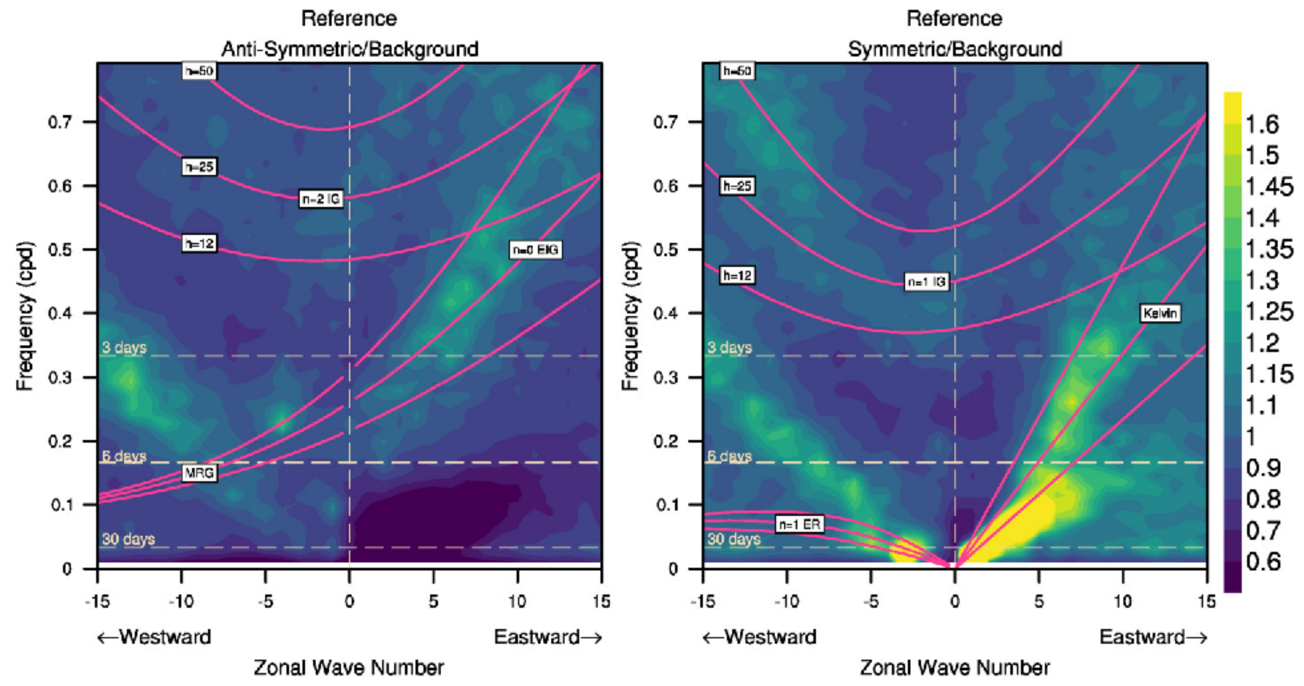


Reed et al (2021)

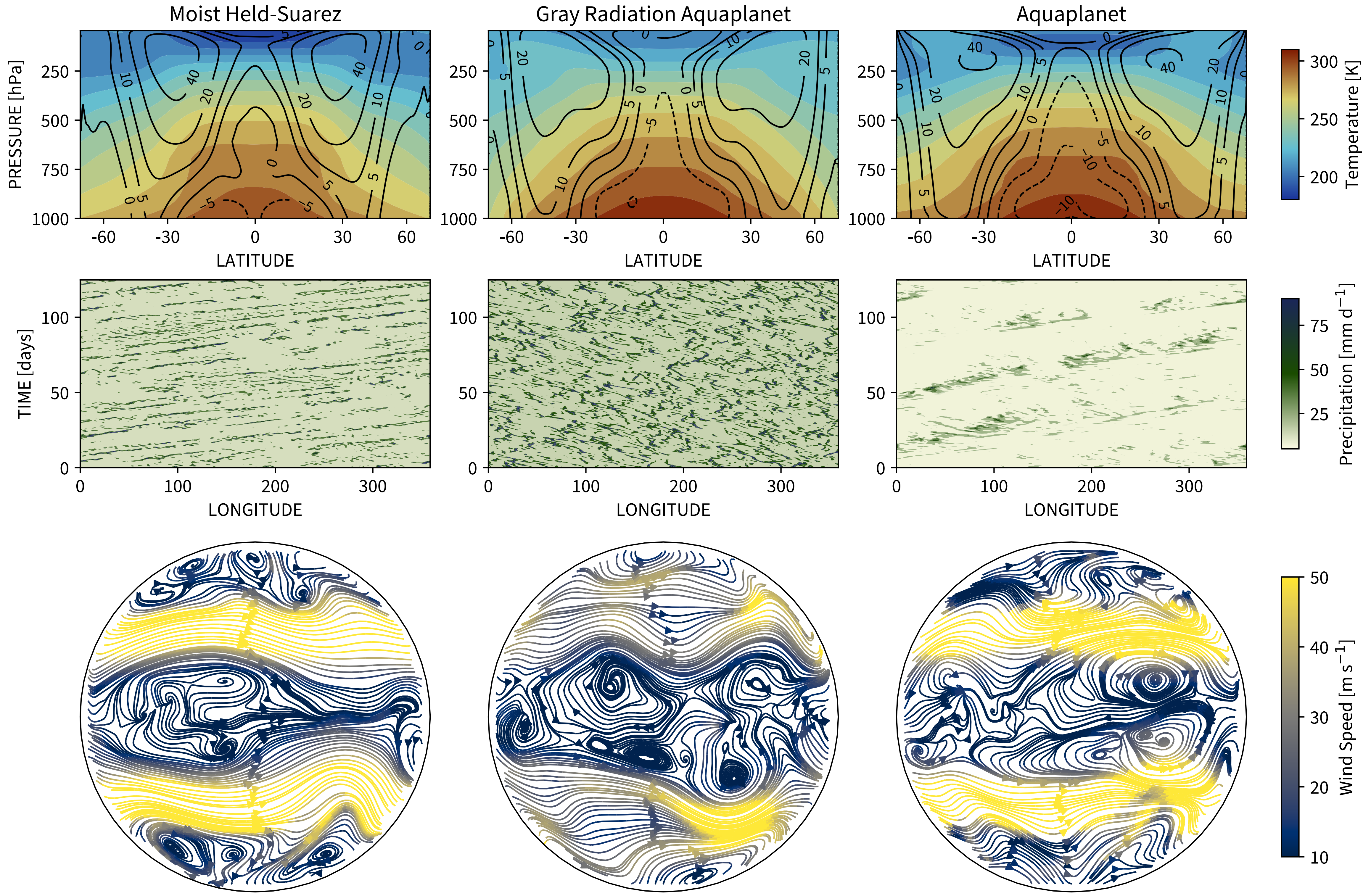
The atmosphere model hierarchy

Aquaplanet

- Aquaplanet
  https://www.cesm.ucar.edu/models/simple/aquaplanet
- Full CAM4, CAM5, CAM6, CAM7 physics.
- Water covered Earth.
- Prescribed SSTs or slab ocean
  (or specify via netCDF file).
- Typically: no seasons, no sea-ice, no aerosol
- Compsets: QPCχ, QSCχ, $\chi \in \{4, 5, 6, 7\}$
- ***Good for*** many applications, high signal-to-noise



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

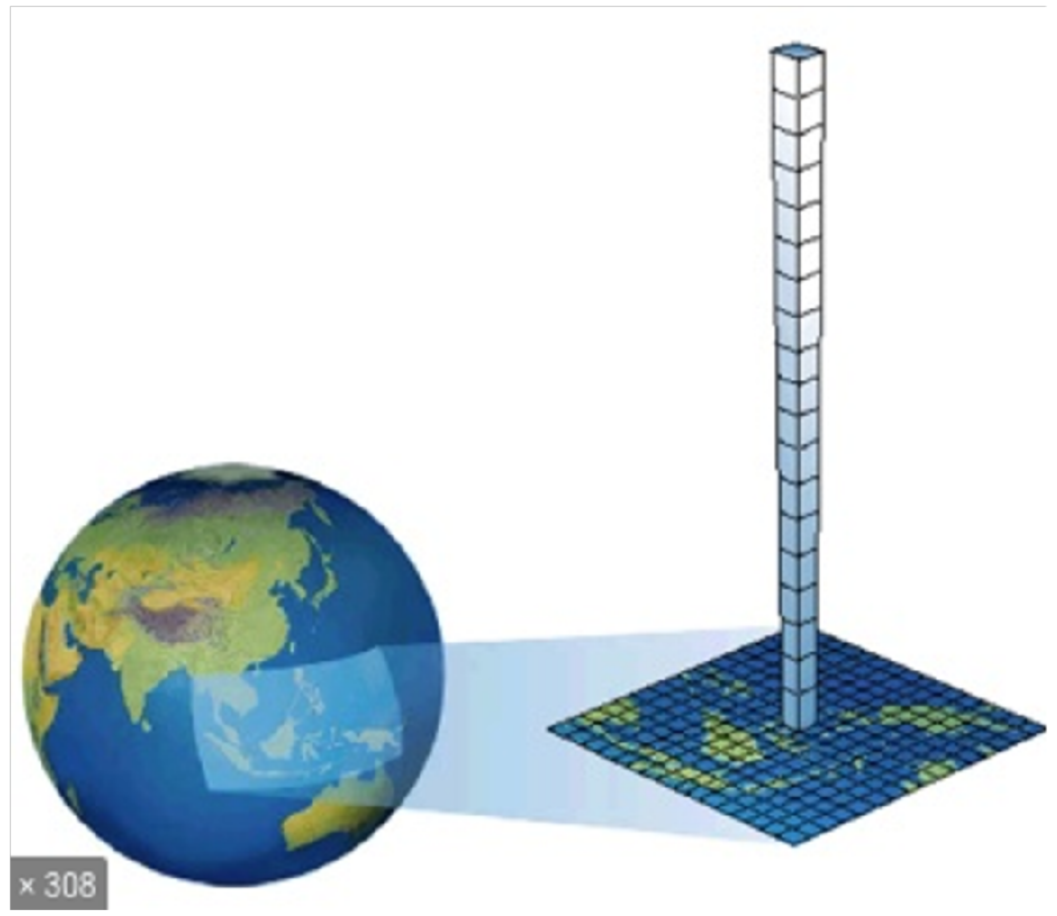


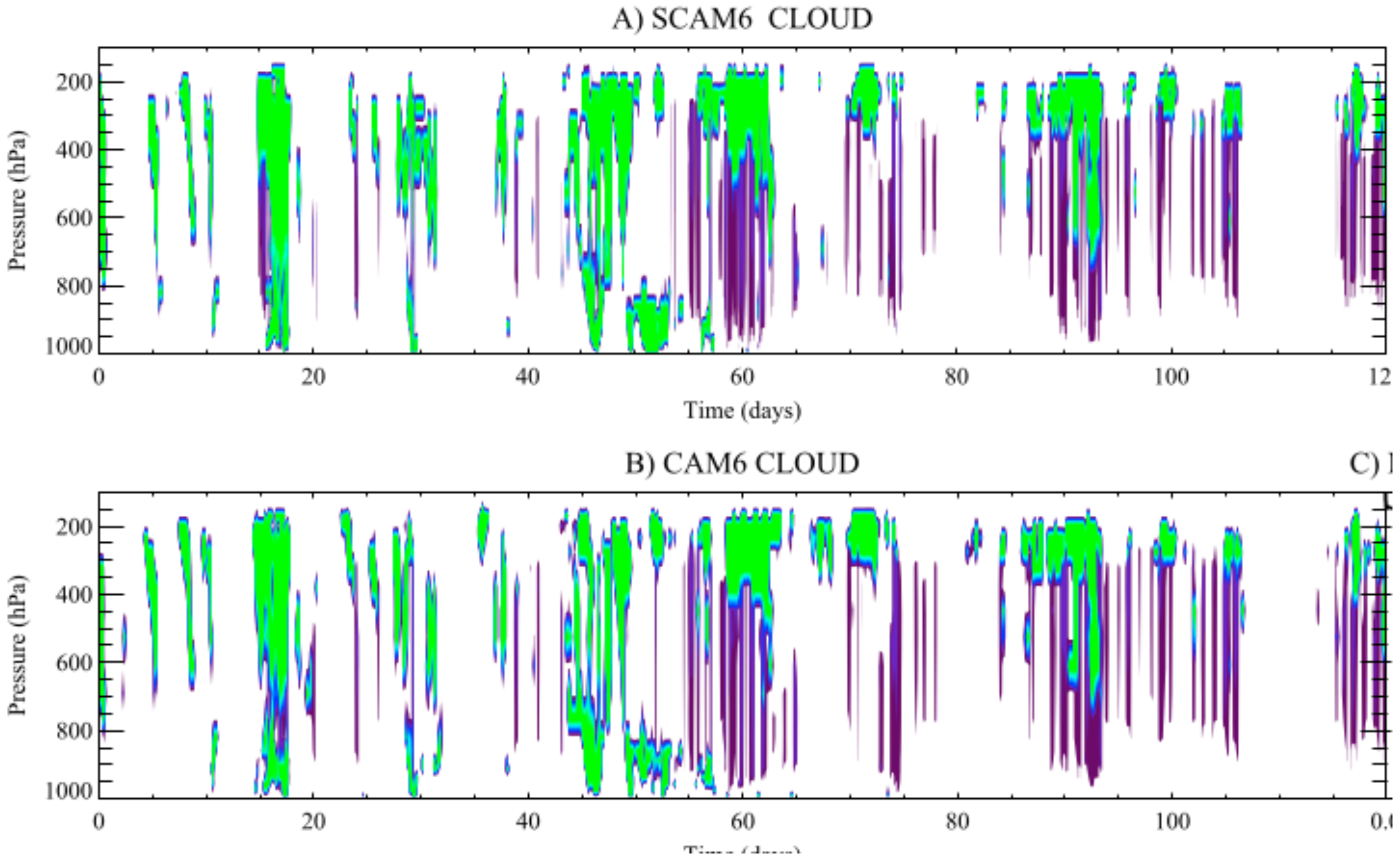
Reed & Medeiros, *Ency. Climate Sys. Sci.*

The atmosphere model hierarchy

Single-column model

- Single Column Atmospheric Model (SCAM), Gettelman et al 2019 https://www.cesm.ucar.edu/models/simple/scam
- Full CAM physics
- Large scale tendencies prescribed from either observations or a simulation.
- Compset: “FSCAM”
- ***Good for*** parameter sensitivity studies to explore how the physical parameterizations behave under different climates and different parameter settings.



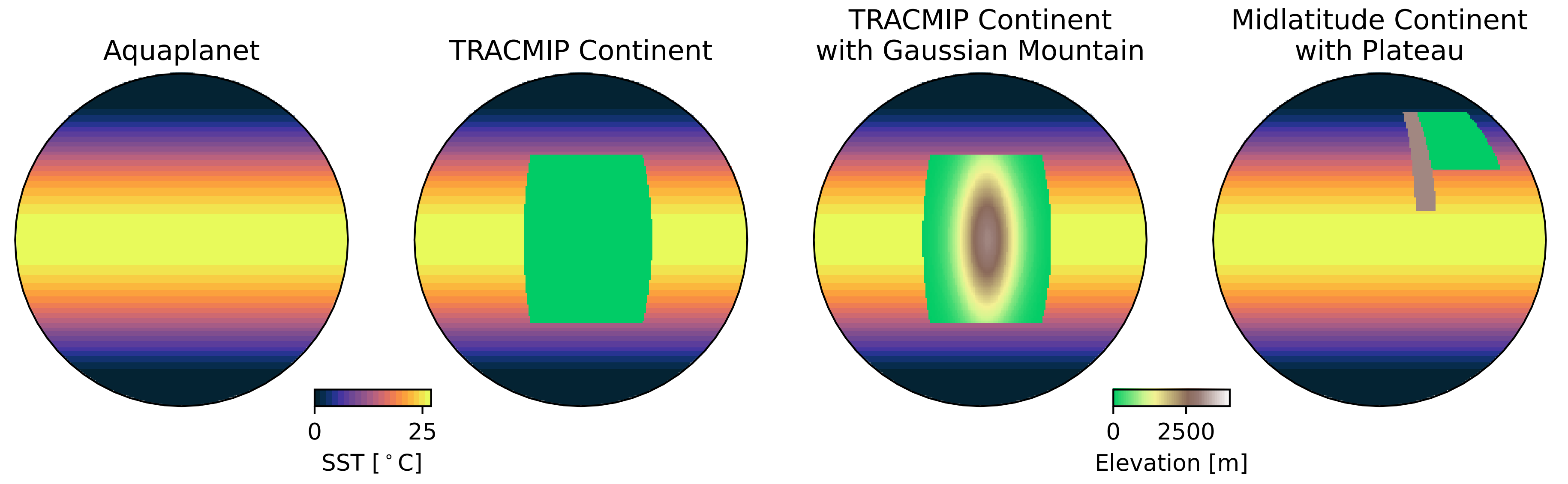


Gettelman et al. 2019

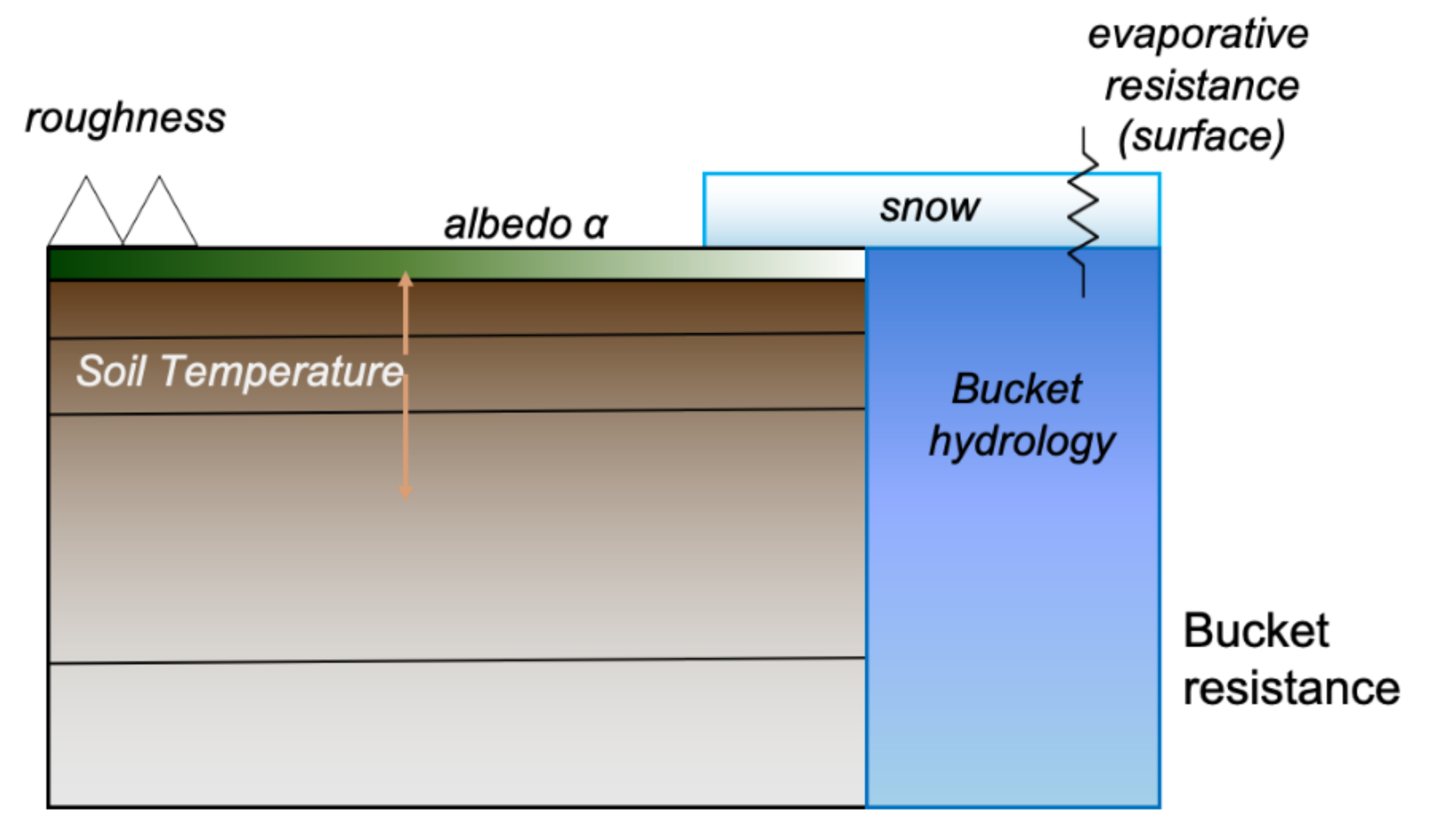
Idealized Land Configurations

from jello to SLIM

- hack the aquaplanet, like in TRACMIP
  - modify slab ocean to occupy area
  - modify albedo, evaporation, roughness
- SLIM (The Simple Land Interface Model, Laguë et al 2019)
  - Solves linearized bulk surface energy budget coupled with soil temperatures and bucket hydrology.
  - Prescribed: Albedo, 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.
  - Implementation into CESM is *almost* complete.



Reed & Medeiros, *Ency. Climate Sys. Sci.*



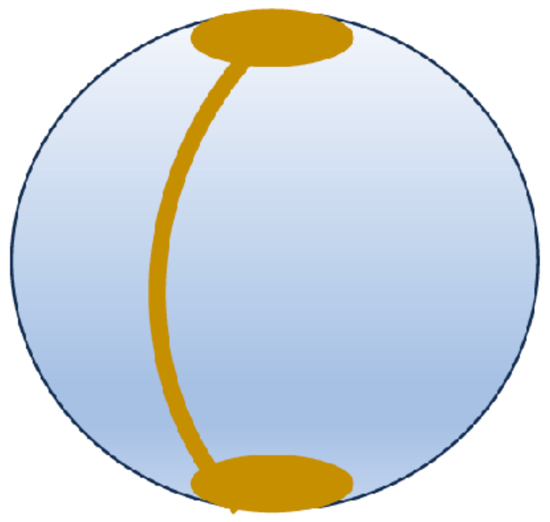
Coupled idealized modeling

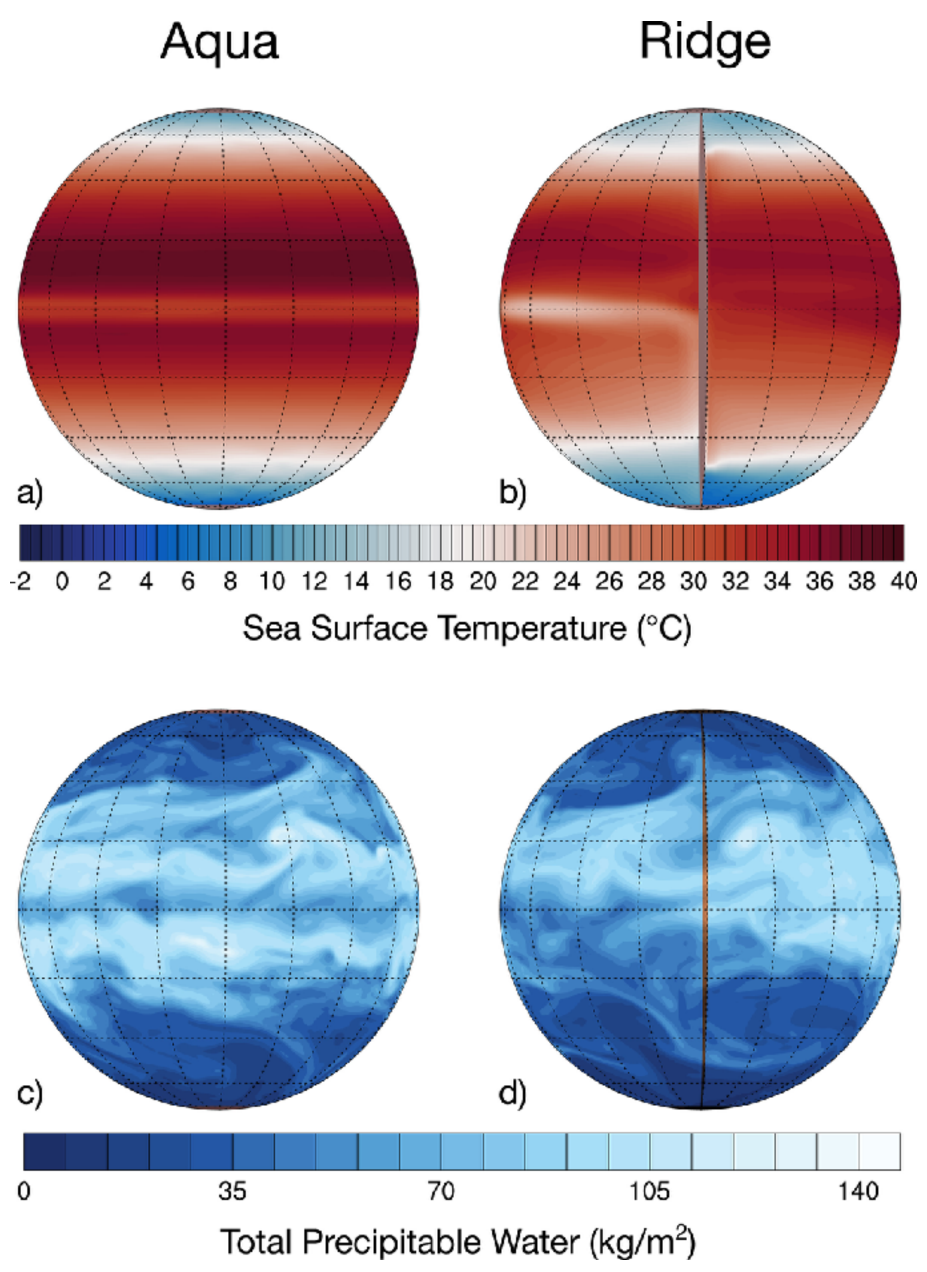
emerging capabilities with CESM

- 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

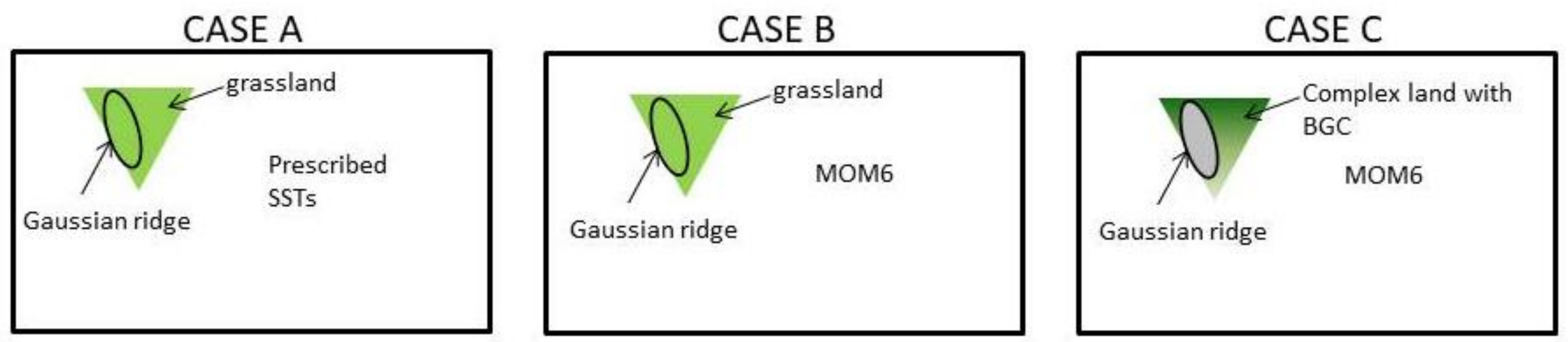
- New tool: VisualCaseGen (Altuntas, Simpson, et al.) www.cesm.ucar.edu/models/simple/coupled/VisualCaseGen

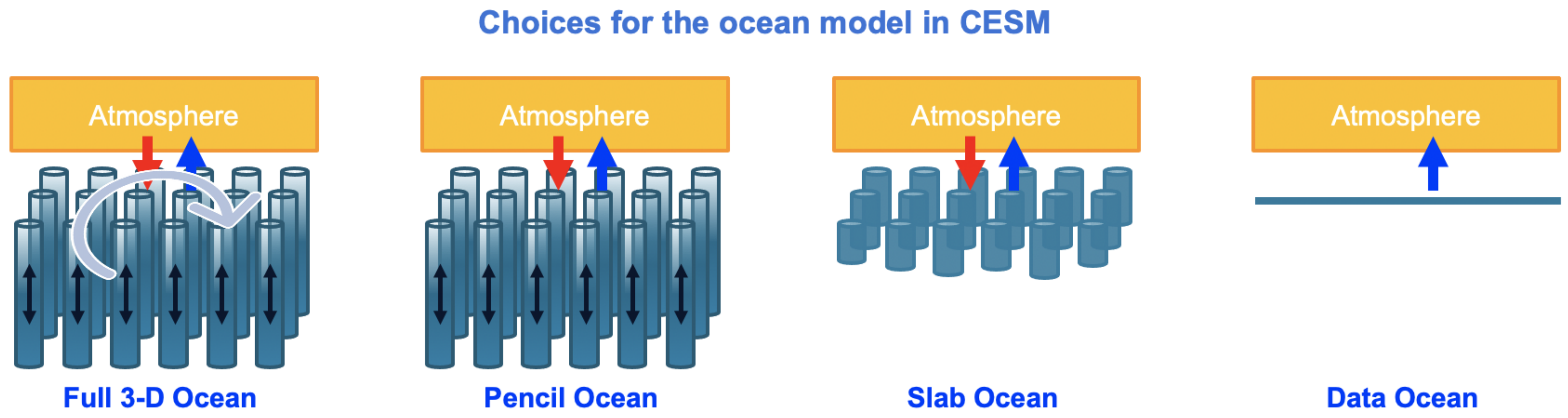
- Idealized ocean “pencil model” (Kwon, Lima, Danabasoglu)





Wu et al. 2021





Simpler models in CESM

Wrap up

- 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 even run on a laptop.
- They are well documented with comprehensive instructions for how to modify them.
- See the simpler models website: https://www.cesm.ucar.edu/models/simple
- Simpler Models on DiscussCESM: https://bb.cgd.ucar.edu/cesm/forums/simpler-models.161/
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