Constraining the optimized random walk of cloud modeling: Idealized frameworks in CESM

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NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF

Outline

- Description of the CESM Hierarchy (or Palette)
- Using different frameworks for cloud development
- Summary and Lessons Learned

- Start with a ‘framework’ for how to build an earth system

One way to build an Earth System….

Genesis 1:1: In the beginning,
God created the heavens and the earth

Heavens first: Dry dynamical core, no forcing (idealized physics)

Then the earth (surface drag)

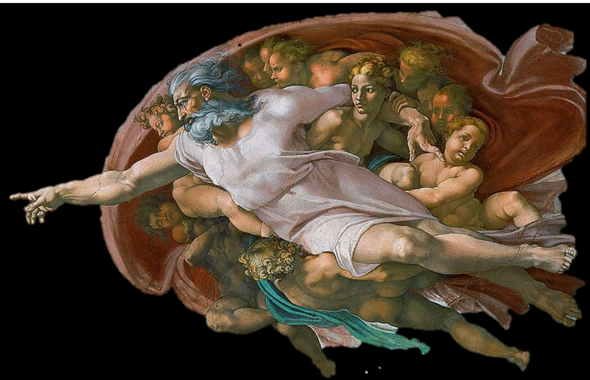
Then God Said:

$$\oiint \vec{E}\,\partial\vec{s} = \frac{Q}{\epsilon_0}$$

$$\oiint \vec{B}\,\partial\vec{s} = 0$$

$$\oint \vec{E}\,\partial\vec{l} = \oiint \frac{\partial\vec{B}}{\partial t}$$

$$\oint H\,\partial\vec{l} = i + \epsilon\,\frac{\partial\vec{B}}{\partial t}$$



And there was light

Radiative transfer (Newtonian cooling)

Baroclinic lifecycle configuration (and many more besides)

End of the first day.

The Rest of the Story

Day 2:

(Troposphere)

Genesis 1:7: “Then God made the firmament and divided the waters from below the firmament from the waters above“

(Ocean) (Clouds)

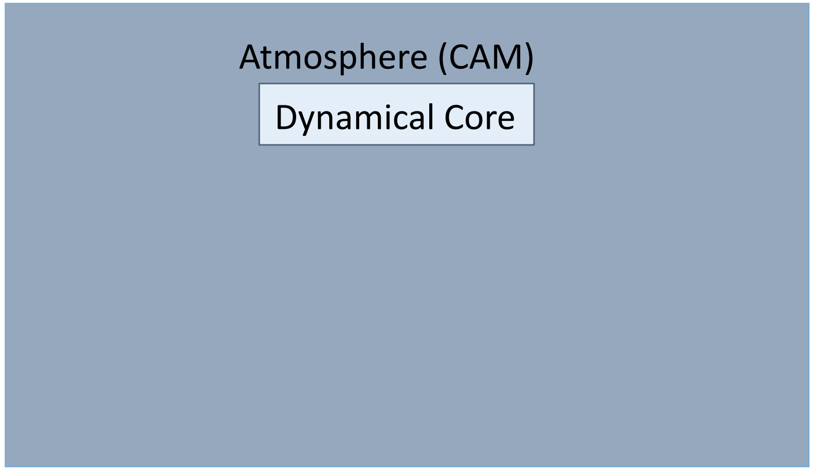
Now we have moist physics and an Aquaplanet

And that was the second day

Day 3:

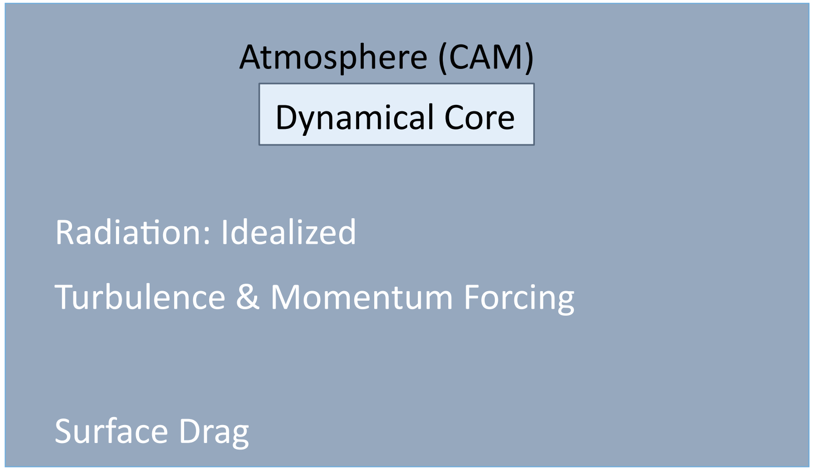
- 1:9: And God said, “Let the waters under the heaven be gathered together unto one place, and let the dry land appear”. And it was so.
- Note: Land and ocean do not appear until day 3

Idealized Atmospheres: Dynamics only

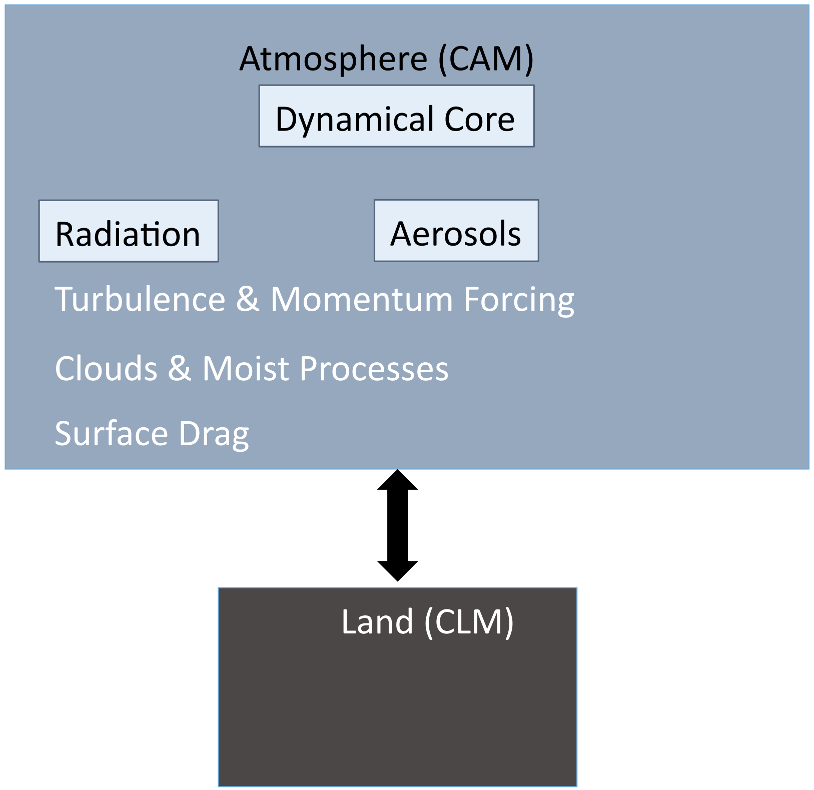


Idealized Atmospheres: Baroclinic

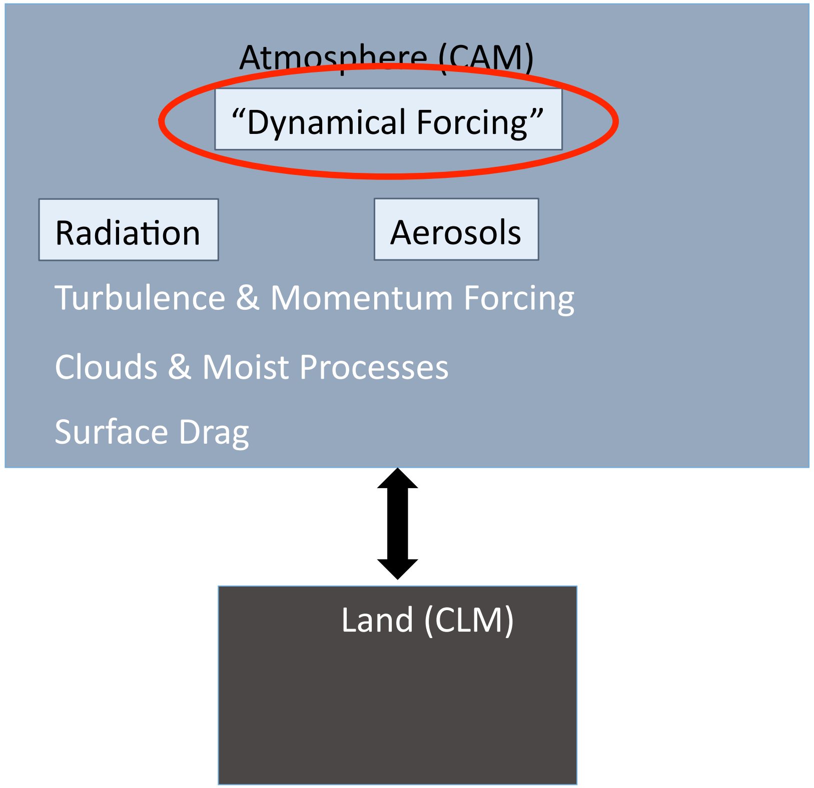
Held-Suarez



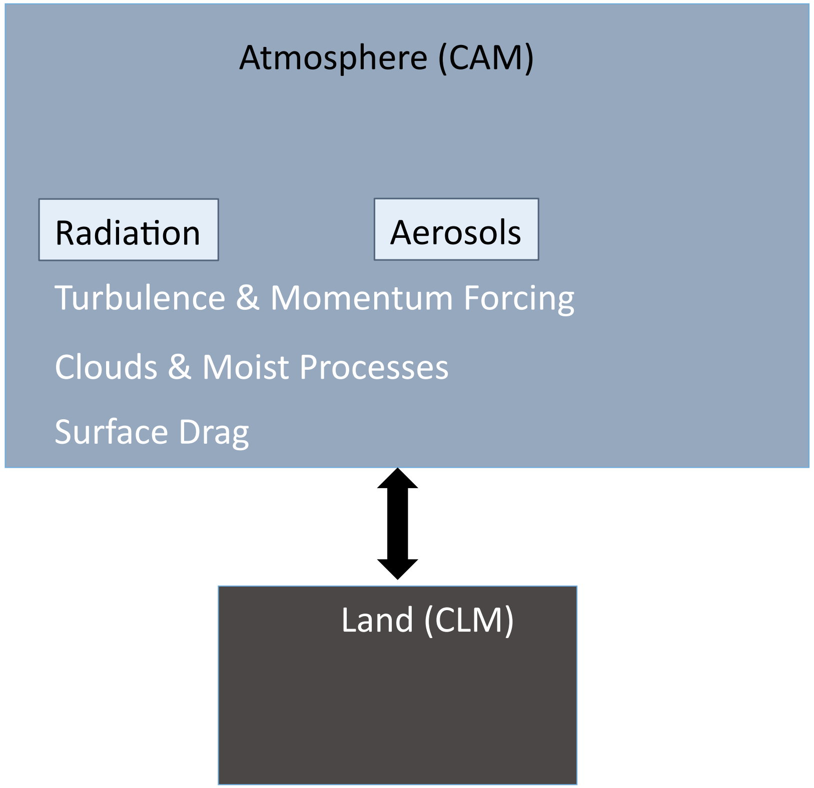
‘Full’ Atmosphere Model



Idealized Atmospheres: Simplified Dynamics



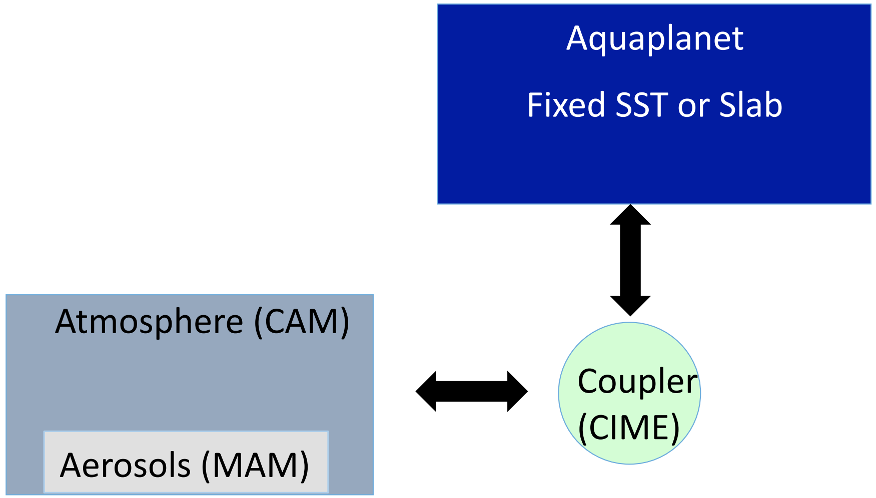
Idealized Atmospheres: Simplified Dynamics



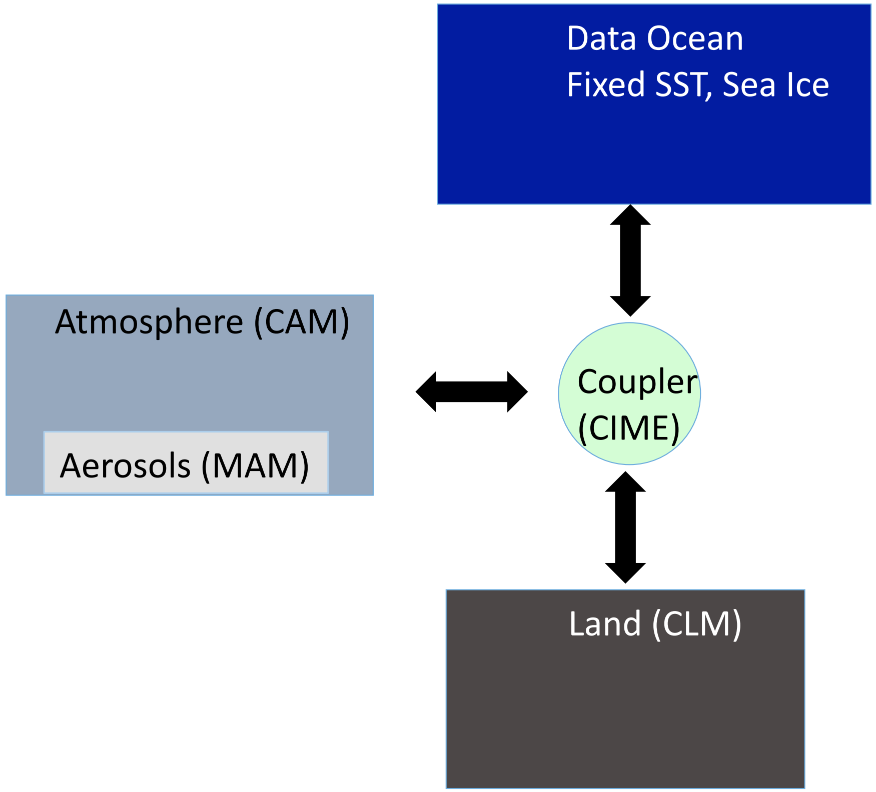
"Dynamical Forcing"

Unit Tests (single parameterization)
Single Column
Specified Dynamics (Nudging)
Forecast/Hindcast

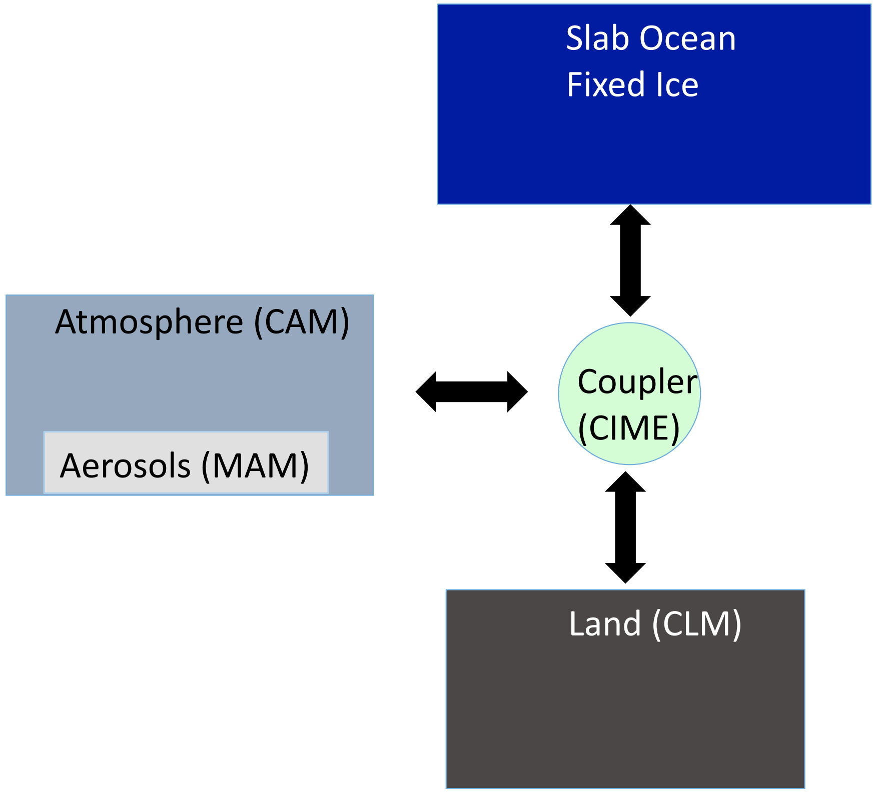
CESM: Atmosphere, Fixed Surface



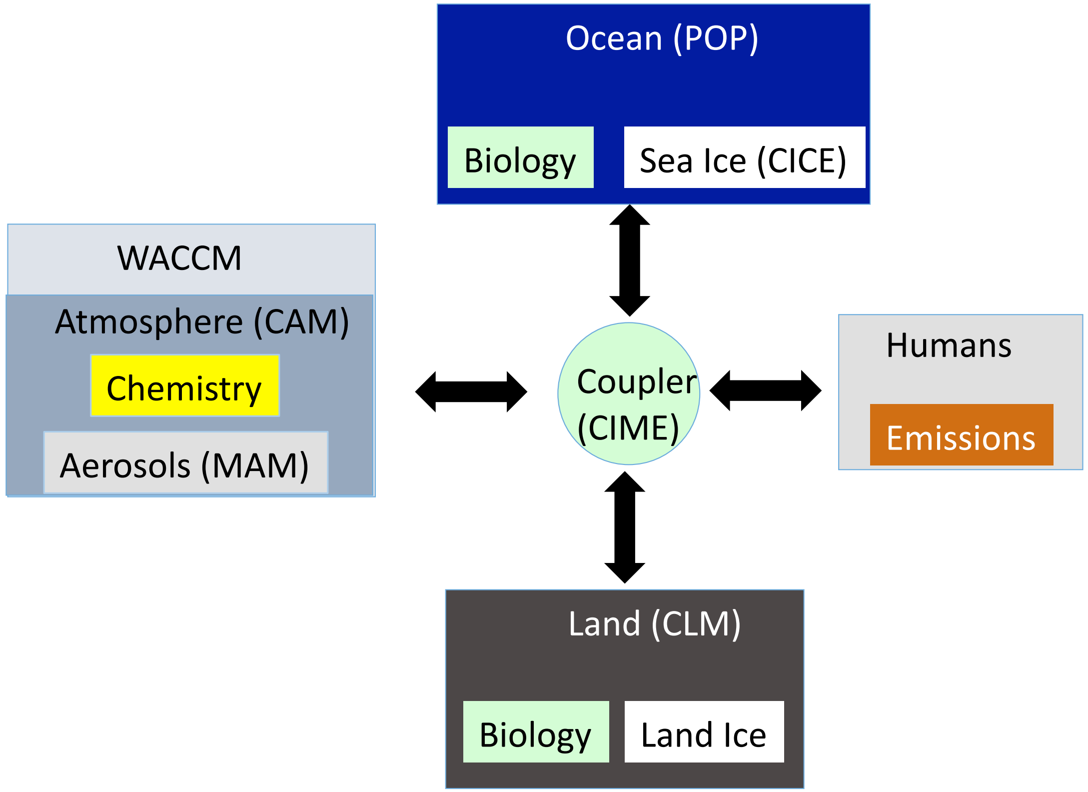
CESM: Atmosphere, Data Ocean



CESM: Atmosphere, Slab (mixed layer) Ocean

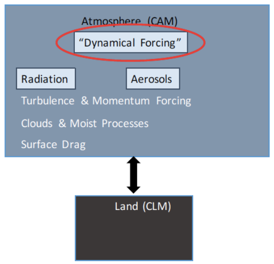


CESM

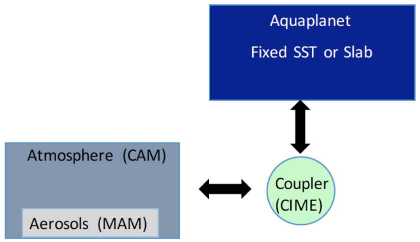

Ocean (POP)
Biology
Sea Ice (CICE)
WACCM
Atmosphere (CAM)
Chemistry
Aerosols (MAM)
Coupler
(CIME)
Humans
Emissions
Land (CLM)
Biology
Land Ice

Hierarchy for Cloud Development
Two Approaches

- Parameterizations: focus on cloud processes
  - Constrain the dynamics and interactions (this talk)
  - Targeted (or limited) cloud feedbacks with the environment
  - Facilitates comparisons to observations
  - Quick turn-around times for sensitivity tests: single effects



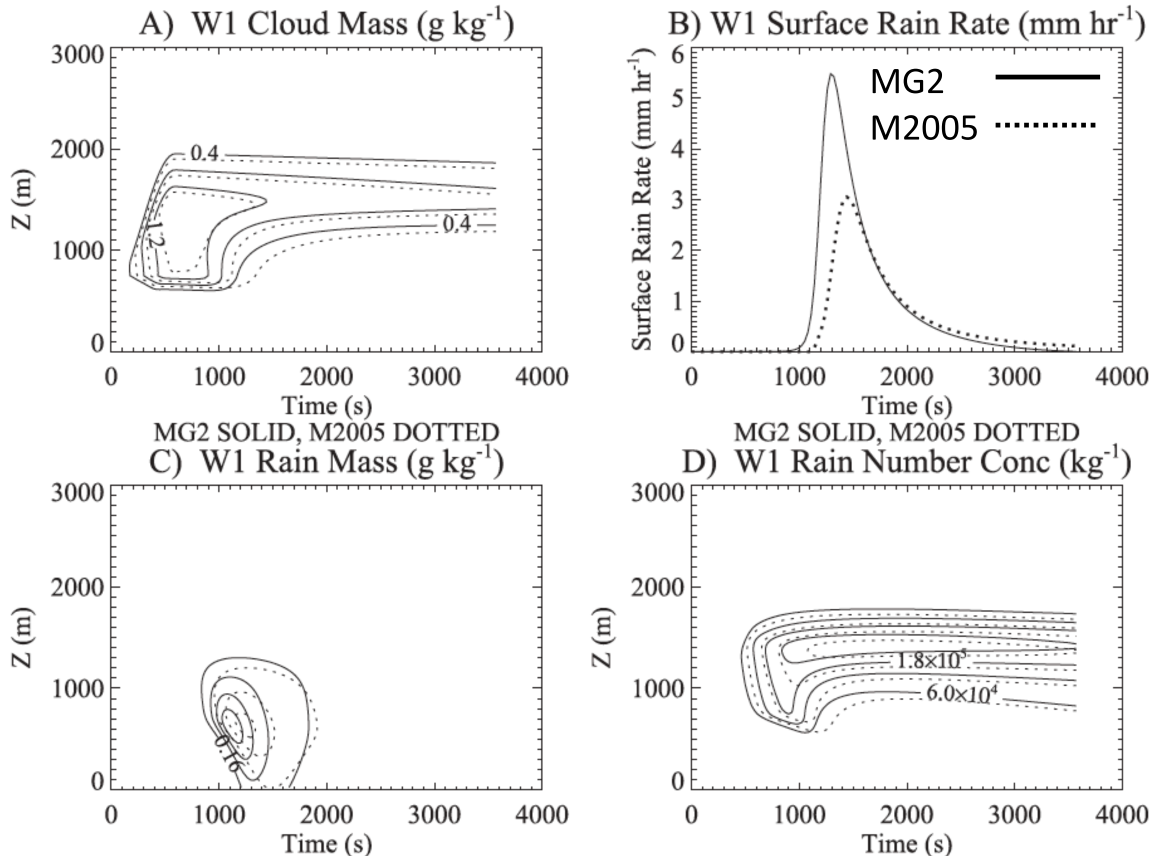
- Cloud interactions with the coupled system
  - constrain the forcing of clouds (simplified surface)
  - but let them interact with environment
  - Good for feedbacks and interactions
  - (Brian Medeiros talk)



Unit Tests
Microphysics Example

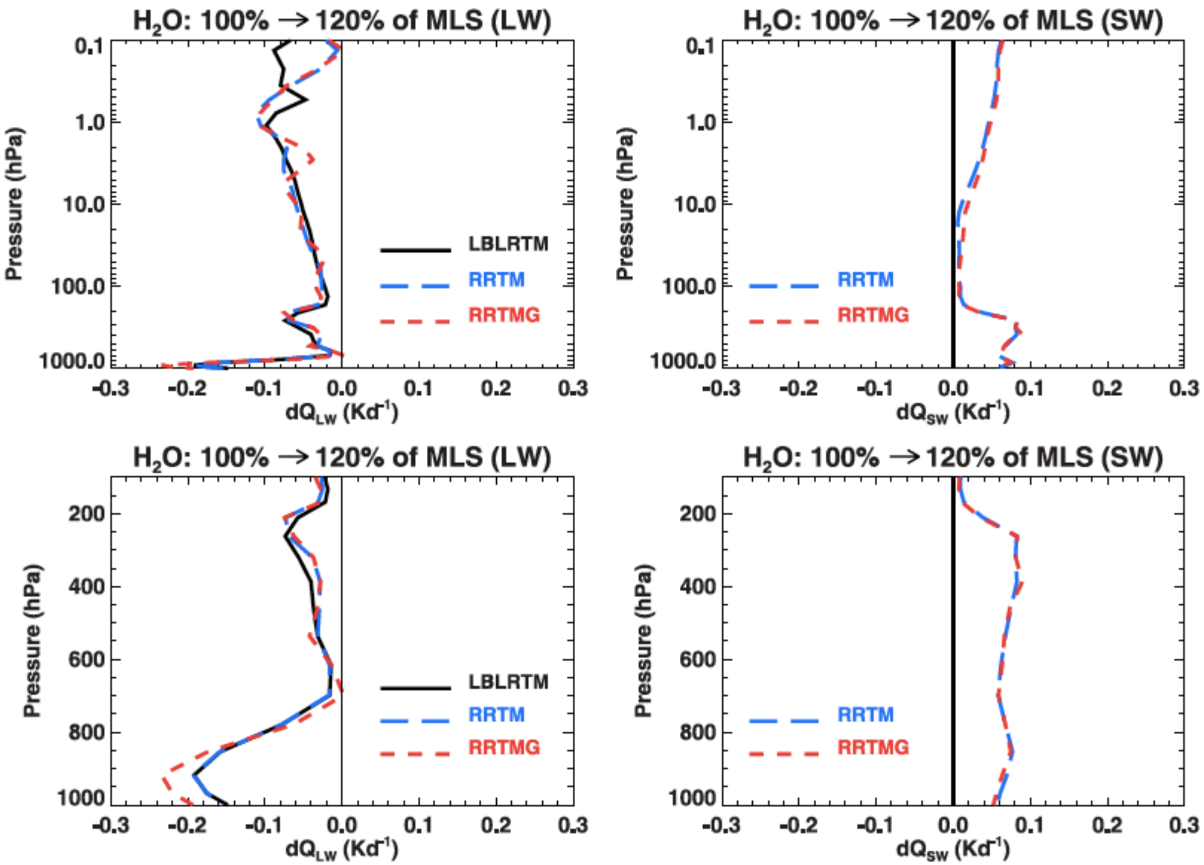
- Off line forcing tests of cloud microphysics
- Use to develop, evaluate and compare schemes
- Example: 2 microphysics schemes. 1-D framework
- Validate (verify?) warm rain case differences
- Turns out this is due to saturation vapor pressure definitions

Gettelman and Morrison 2015, J. Climate



Unit Tests
Radiative Models

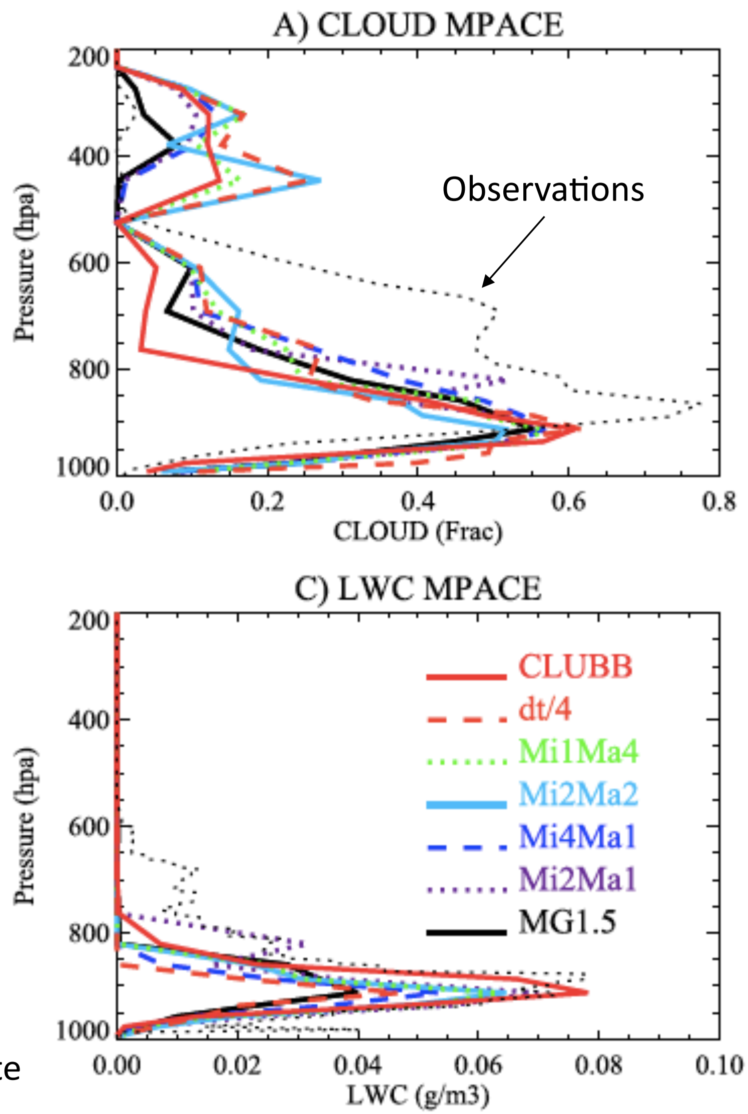
- Can also compare to 'reference models'. Sometimes LES is called a 'reference'
- But some parameterizations have more accurate solutions, e.g. radiative transfer
- Example: Evaluation of RRTMG against RRTM and Line-by-Line code (LBLRTM)
- This is much harder to do for cloud optics



Iacono et al 2008, JGR

Single Column
Parameterization Evaluation

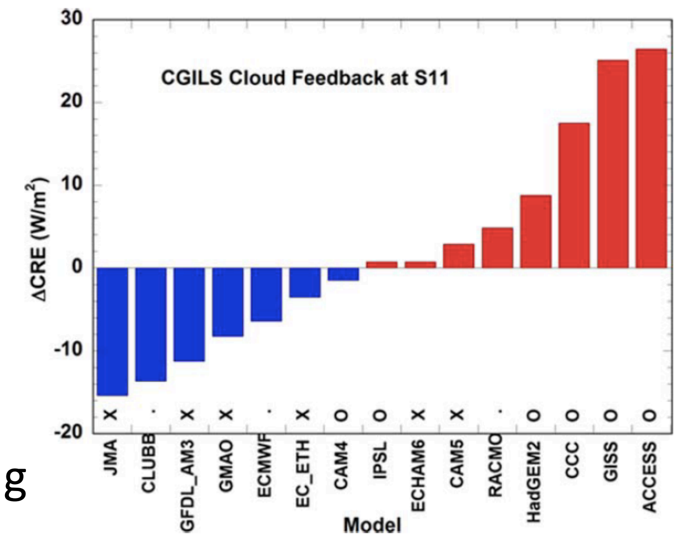
- Constrain the dynamics to one region (column) where observations exist
- Example: Testing coupling of microphysics and large scale condensation (Macrophysics)
- Goal: Evaluate against observations
- Arctic multi-level clouds
  - MPACE (October, Barrow)
- Note: can also do for long simulations (years) to get statistics



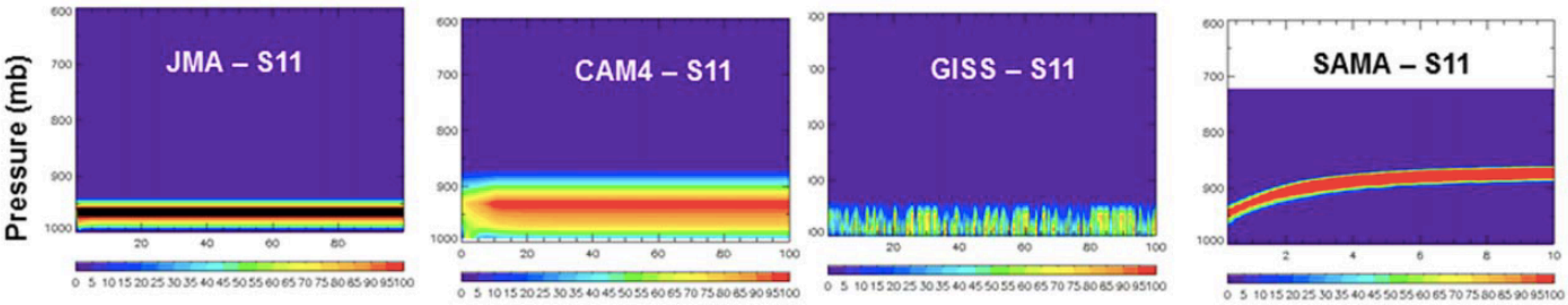
Gettelman et al 2015, J. Climate

Single Column
Feedback Studies

- Run a particular case with perturbations
- Example: CGILS study of feedbacks
- Bottom: Different model simulations of one point
- Right: Model Cloud Response to +2K SST increase
- An ‘estimate’ of cloud response to environmental forcing

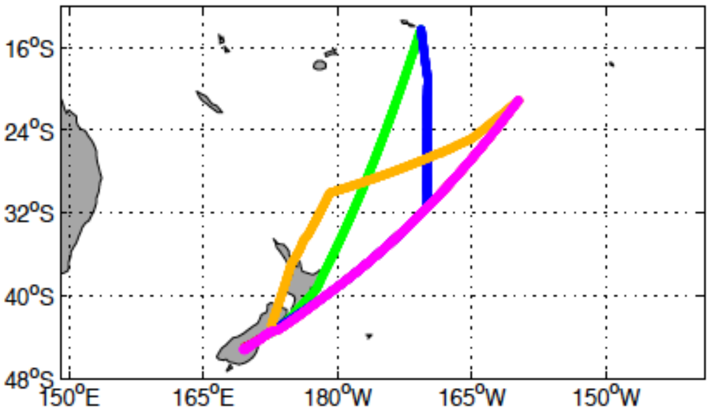


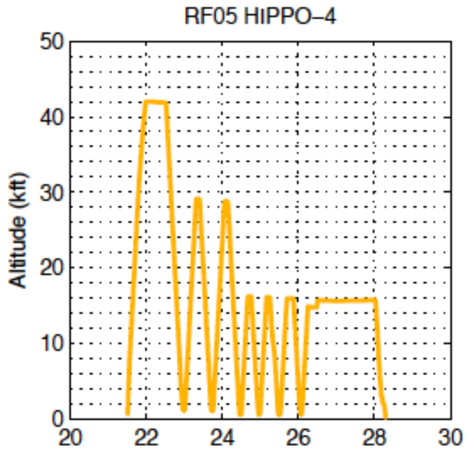
CGILS (Zhang et al 2013, JAMES) Point S11 (Cumulus under strato-cumulus)



Nudging

- Commonly used for tracer advection studies ('CTMs')
  - Water is a tracer, it actually works pretty well
- Simulate individual events, at one point, or many points
- E.g.: Aircraft observations, or a particular event (storm) seen from Satellite
- Example: NSF G-V Aircraft flights over the Southern Ocean looking at Cloud Microphysics





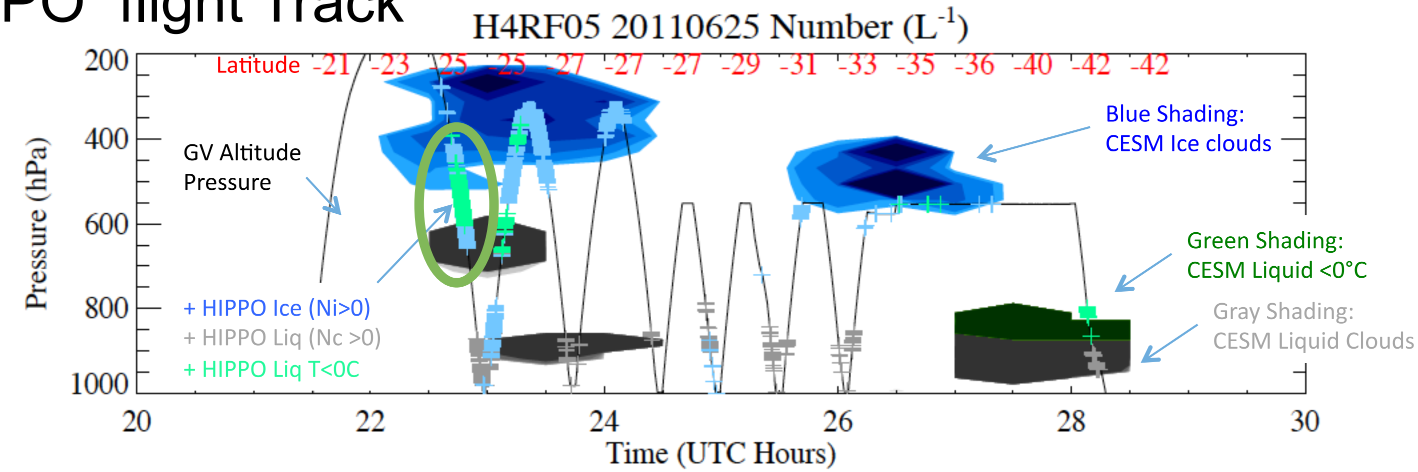
Example: Research Flight: June 2011 Specified Dynamics version of CESM to simulate a particular day. Force winds and Temps. What do the clouds do?

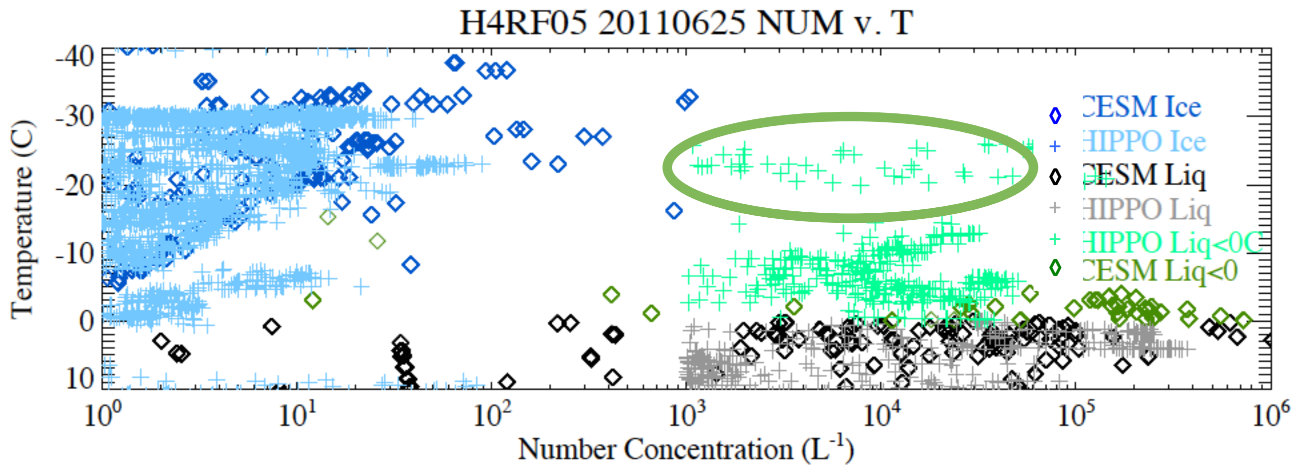
Nudging

Section along HIPPO flight Track

- Model puts clouds mostly in the right place
- Compare cloud phase and cloud microphysics to observations
- Microphysics is well represented for ice
- But: missing cold super-cooled liquid

SOCRATES Project Plan, 2016

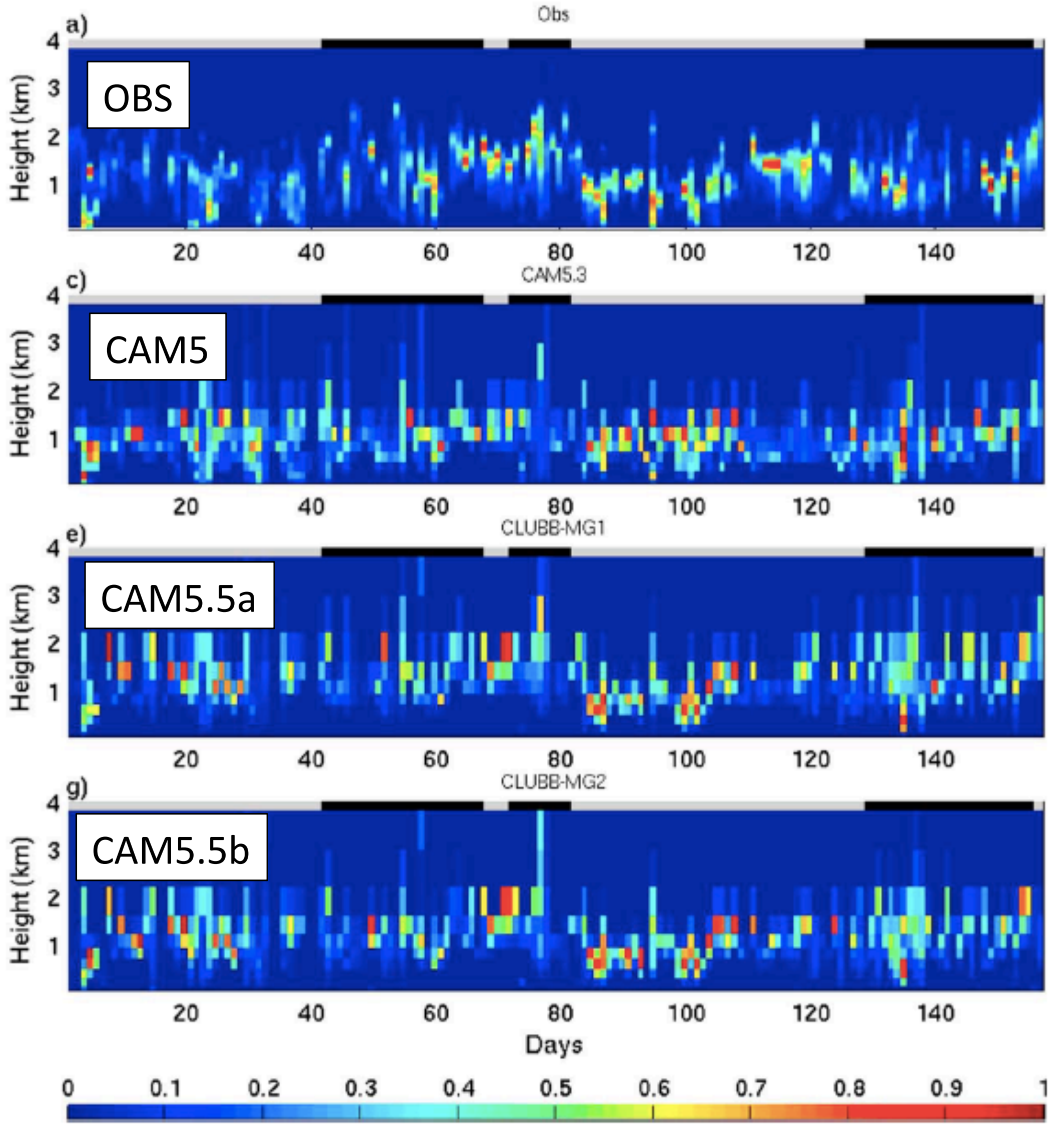




Hindcasts: CAPT

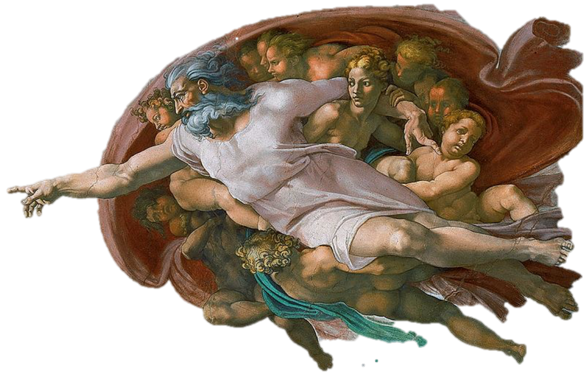
‘NWP’ Type Evaluation

- Set up the model from initial conditions (e.g. ERAI)
- Run forward. Biases in clouds show up in a day (or less)
- But dynamics still ’close’ to initialization
- Example: Marine Boundary Layer Cloud Days over the Azores. Day 2 Forecasts starting from ERA-I
- Evaluate performance of different cloud schemes in CAM
- Can also use for parameter estimation



Zheng et al 2016, JGR

Summary and Lessons



- Lots of ways to build an earth system!
- For clouds: constrain the dynamics for processes
- Constrain the forcing (surface models) for feedbacks
- Use simplified frameworks for cloud development & evaluation
- Start with numerical tests
- Build to realistic tests (Single column, Nudging)
- All the way up to ‘NWP’ Hindcast-type verification (CAPT)