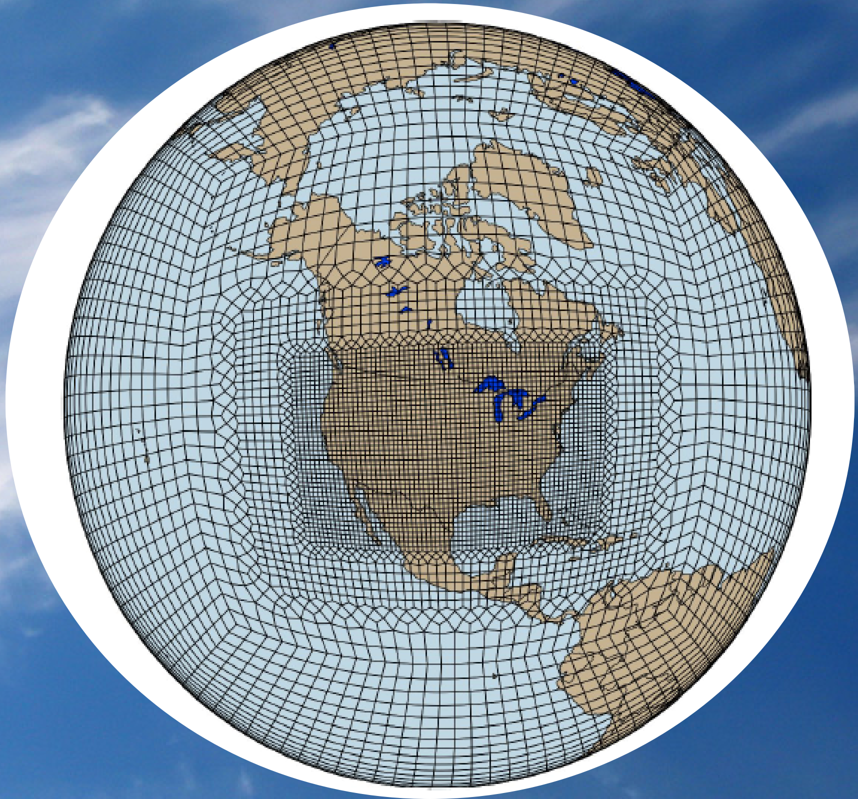
How *not* to build a Model: Coupling Cloud Parameterizations Across Scales

Andrew Gettelman, NCAR



NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

All models are wrong. But some are useful.

-George E. P. Box, 1976 (Statistician)

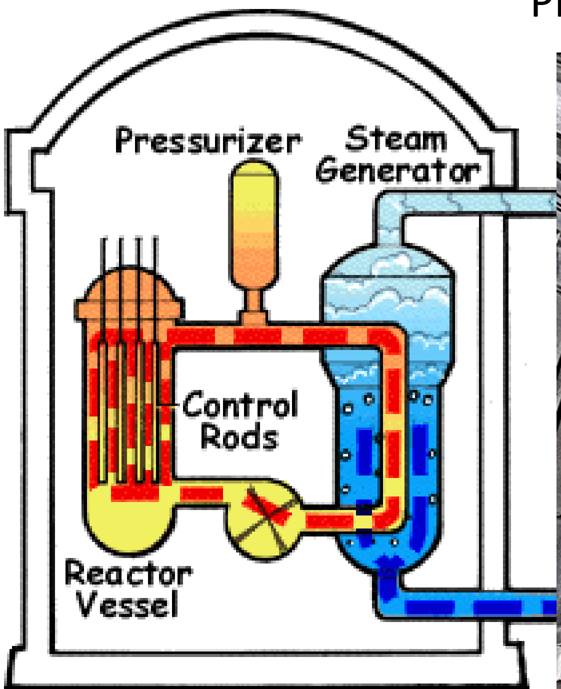
"The Treachery of Images", René Magritte, 1928

How NOT to build a model: Outline

- Philosophy of Integrating Parameterizations
- Optimization of Parameterizations (‘Tuning’)
- Scale issues
- Numerical considerations (clipping and stability)
- Developing a physical parameterization suite across scales
    - CESM development example

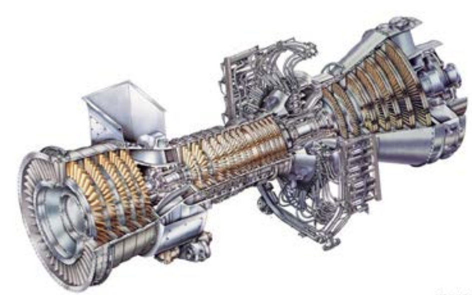
Developers view of an ESM

Dynamical Core

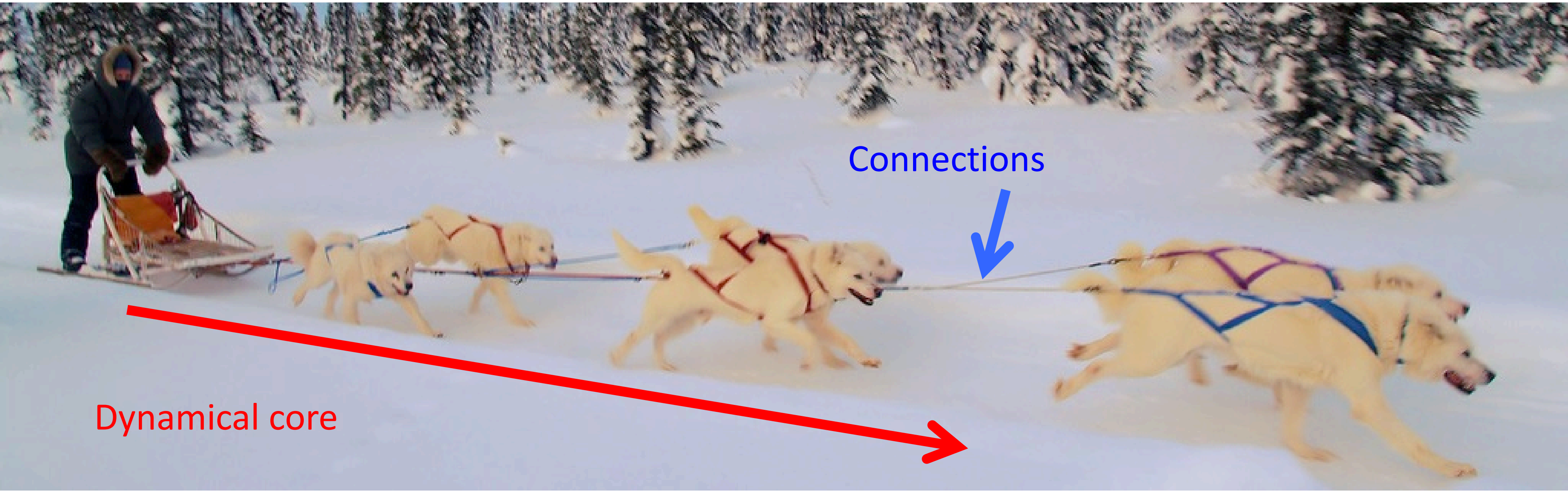


Plumbing that Connects Them

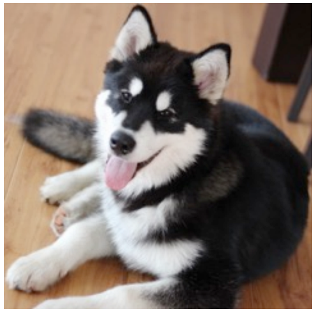
Parameterizations
(Tendency Generators)



A Better View



Parameterizations
(Tendency Generators)

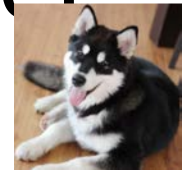


Deep Convection

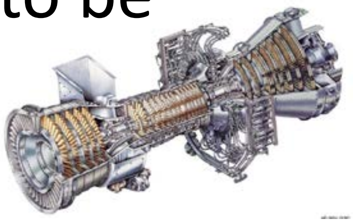
Microphysics

Condensation
/Fraction

How do we develop a model?

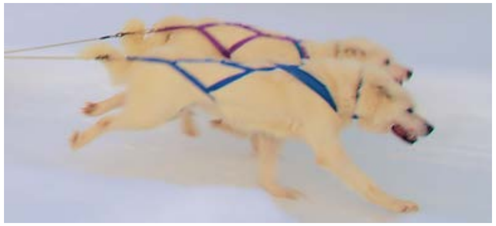


- Parameterization development
  - Evaluation against theory and observations
- Constrain each process & parameterization to be physically realistic



  - Conservation of mass and energy
  - Other physical laws
- Connect each process together (plumbing)

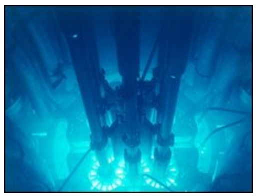
  - Coupled: connect each component model
- Global constraints
  - Make the results match important global or emergent properties of the earth system
  - “Training” (optimization, tuning)



Why doesn’t it work?

- Process rates are uncertain at a given scale

  “all models are wrong…” (uncertainty v. observations)



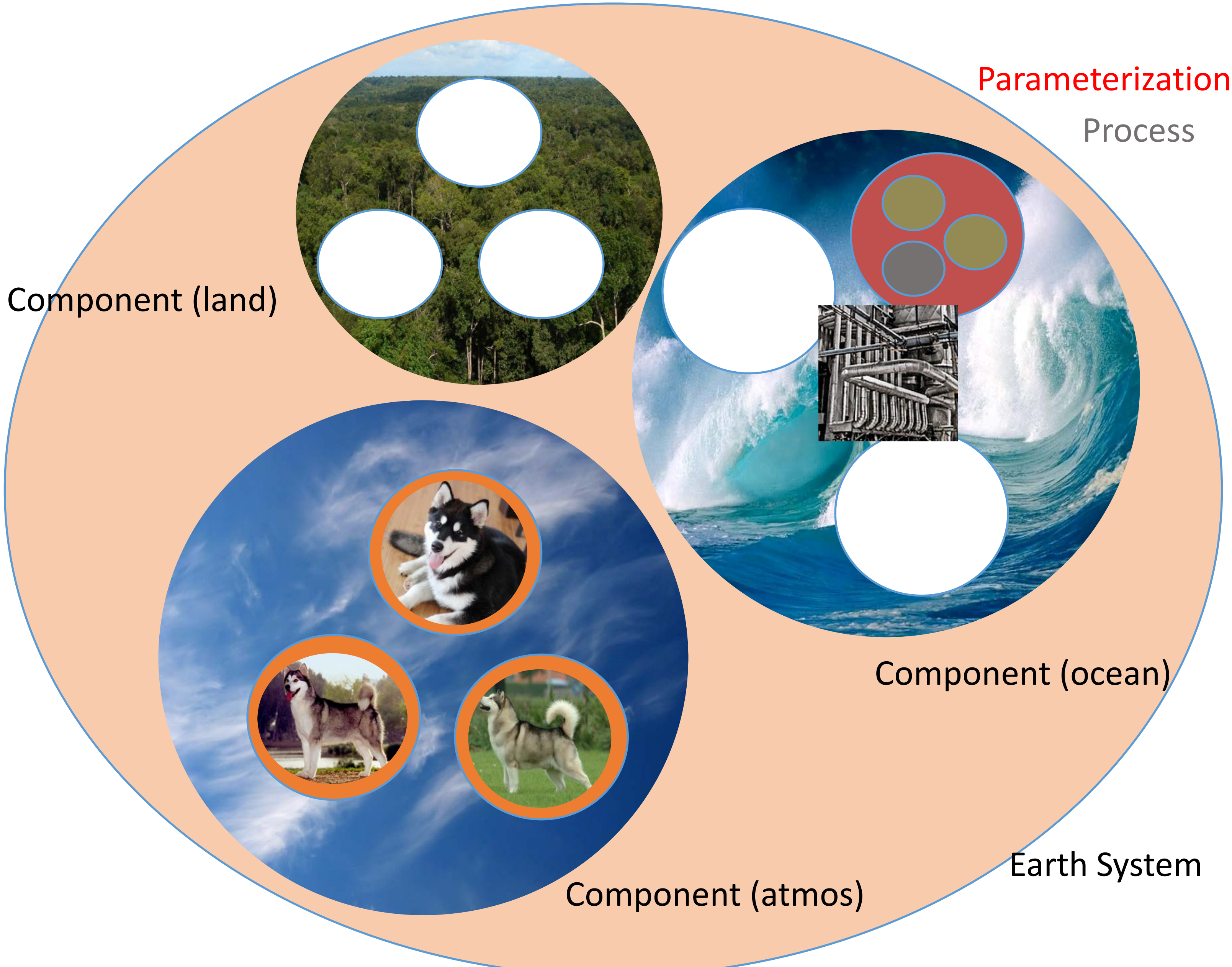
- Problems with the dynamical core

- Problems connecting processes

- Each parameterization is it’s own ‘animal’ & performs differently with others (tuning = training, limits)

Each parameterization needs to contribute to a self consistent whole

Stages of Optimization (Training)

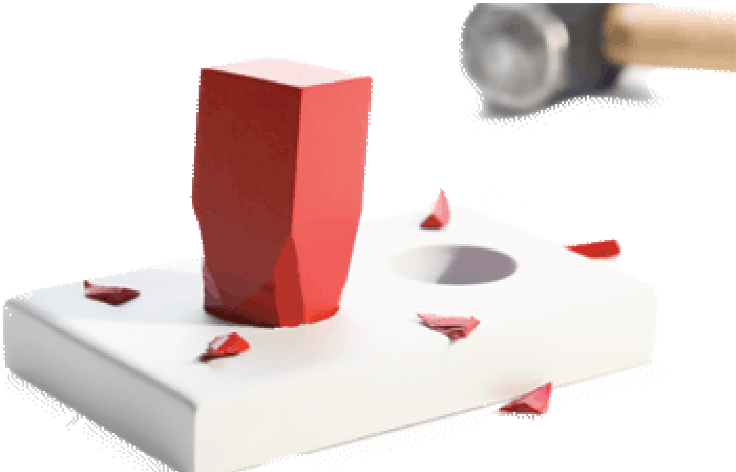


Problems with parameterizations

- Need to ensure (enforce) mass and energy conversion
- Represent sub-grid scale variability
  - This changes with time and space scales
  - Potentially a critical issue
- Couple to other processes
- Example:
  - Multiple cloud schemes (deep conv, condensation, micro)
  - Pass condensation to cloud microphysics
  - Get advective terms and dynamical (U,V) and radiative (T) forcing from dynamical core
- Model state is a push-pull interaction

How do we optimize parameterizations?

- Basic level: adjust (‘clip’) process rates
  - Conservation & numerics issue
- Can also modify the ‘uncertain’ parts of parameterizations
  - Uncertainty comes from imperfect observations
  - Scale dependent
  - Also problems with coupling (push-pull)
- Implicitly: adjust the ‘least certain’
  - Least certain processes
  - Least certain observations

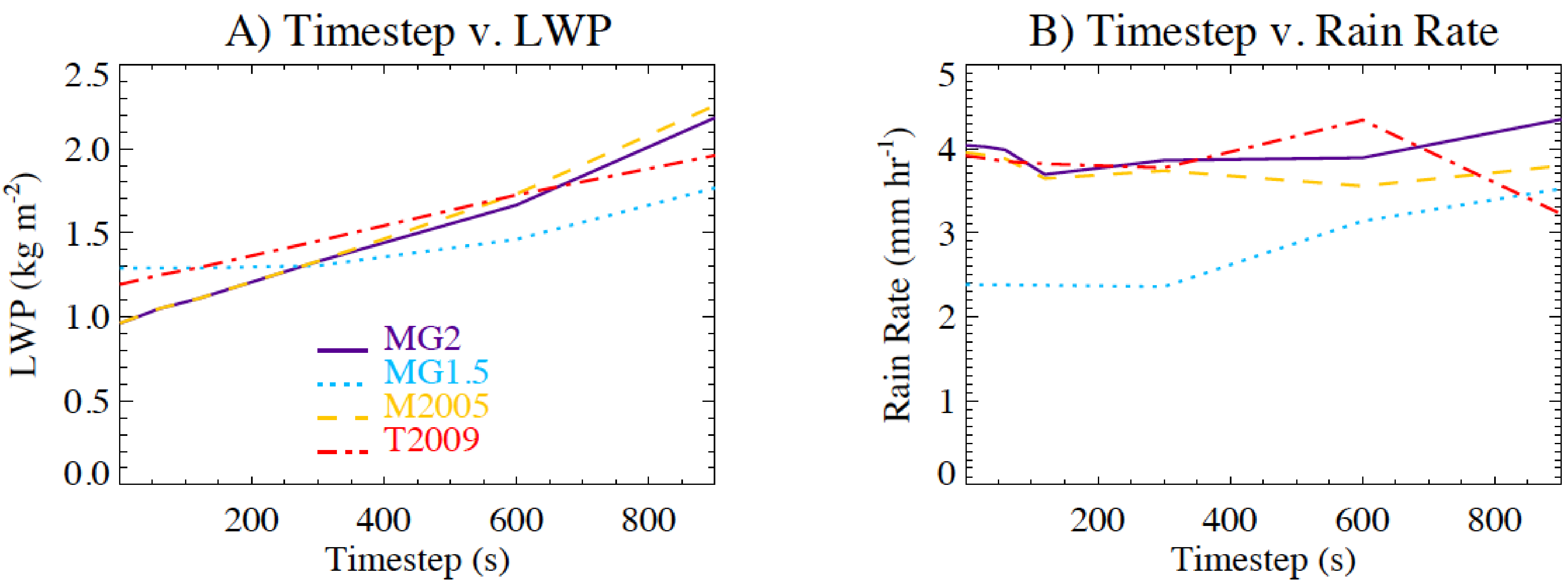


Scale issues

Example: off line sensitivity of cloud microphysics rain rate to time step, with a constant condensation rate: Rain rates are stable, but LWP is not.

Is this surprising? (more condensation per timestep)

Is the parameterization wrong, or coupling to rest of model?



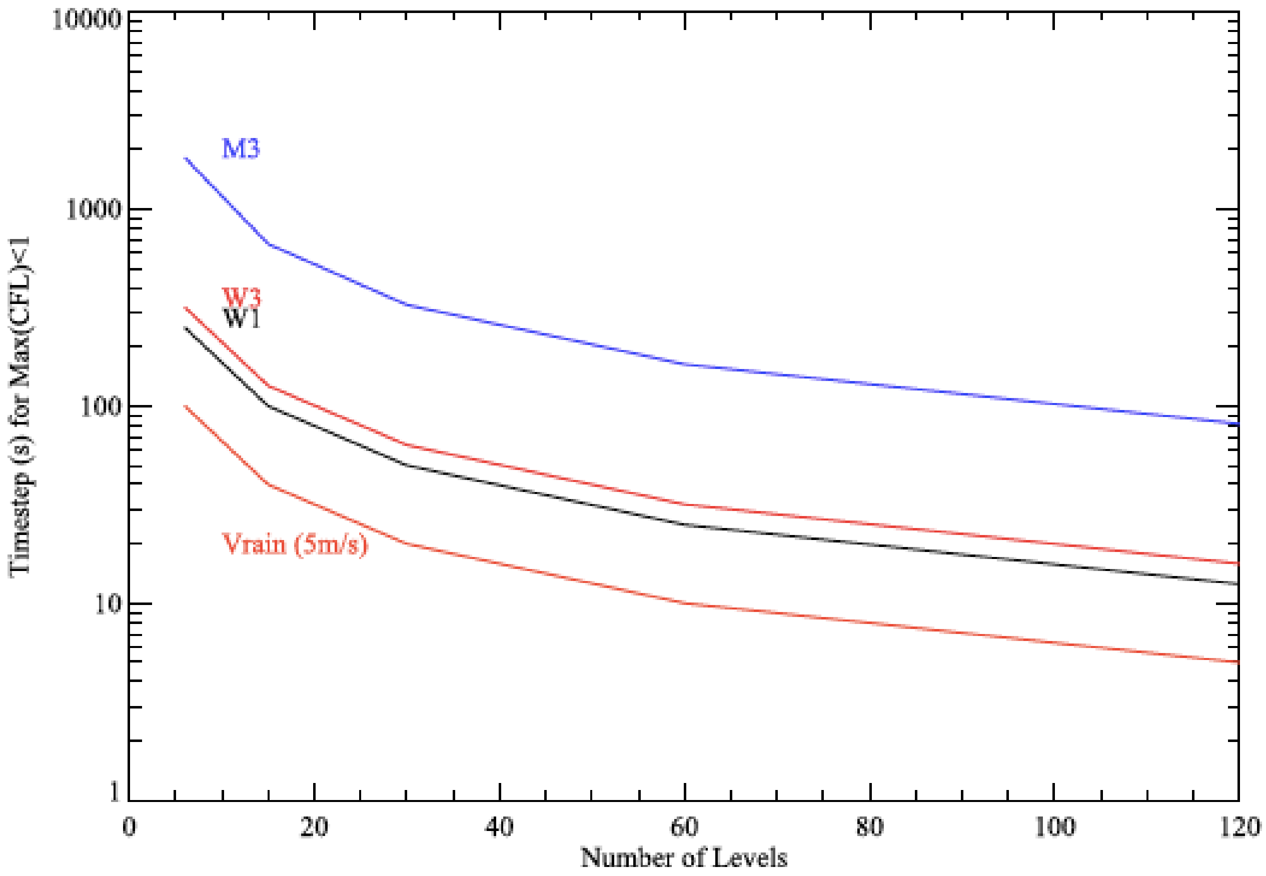
Gettelman & Morrison, 2014, in press, J. Clim

Numerics: Sedimentation

Figure: maximum timestep for satisfying CFL condition with different updraft speeds and fall speeds for rain (5m/s)

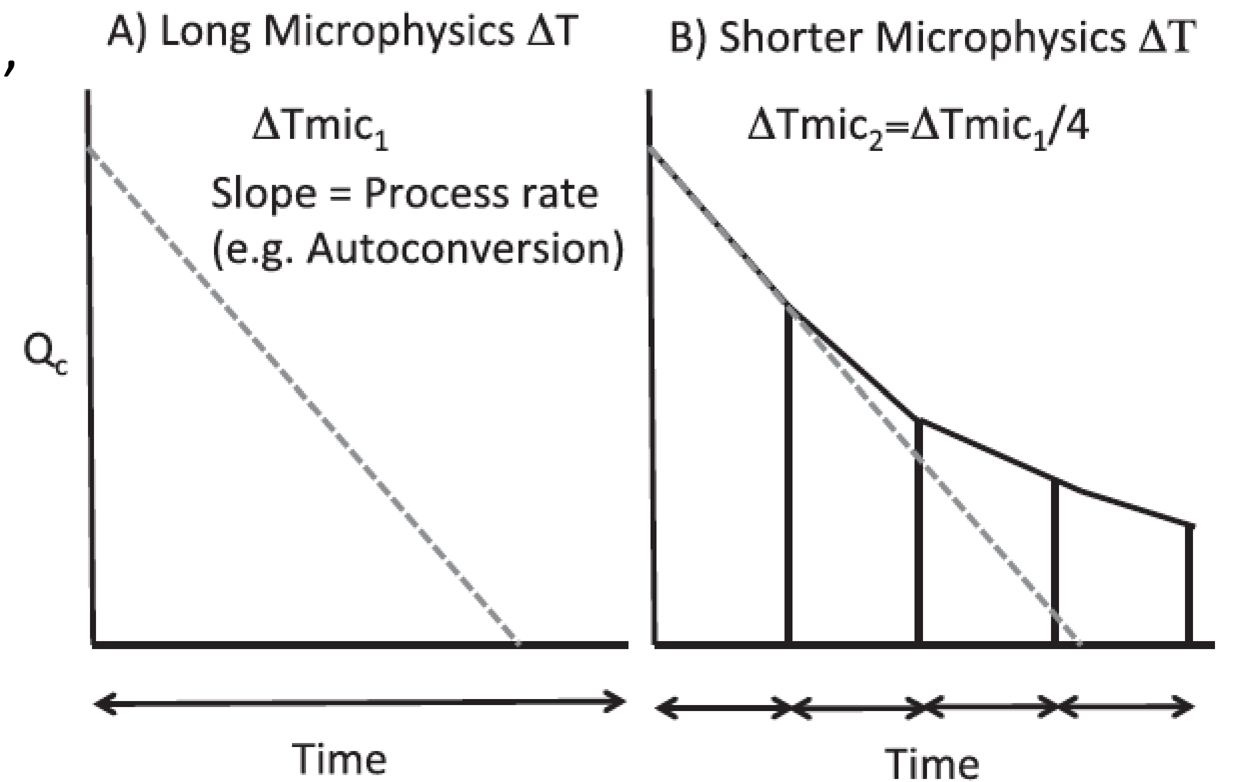
- 1800 s GCM Timesteps
- If rain falls at 1-5 m/s, then in 1 timestep it crosses several levels
- CFL problem for sedimentation
- Control for this in microphysics (sub-steps)

Levels v. Critical Timestep



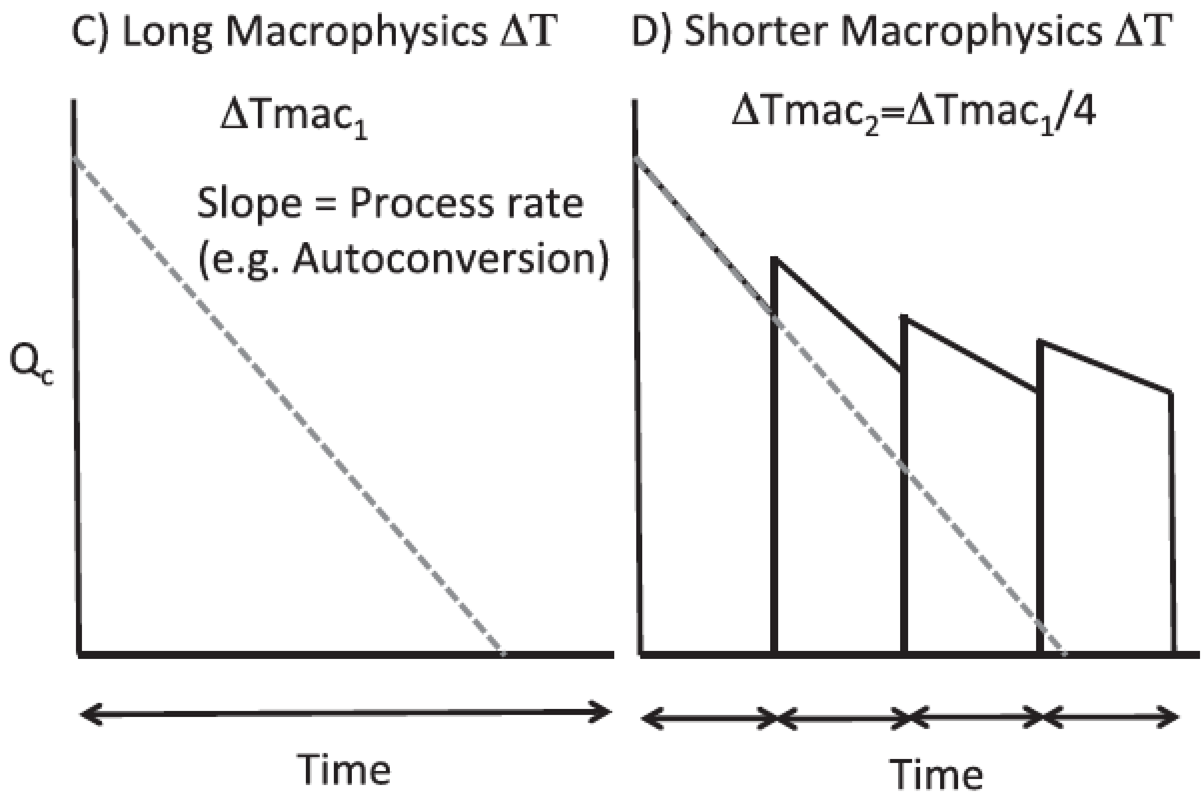
Numerical clipping

- Can ‘run out of water’ with long time steps
- Process rates non-linear: lots of condensation = more autoconversion
- Shorter time steps yield a different solution



Coupling to condensation

- Similar issues occur with condensation itself, and coupling with macrophysics



Physical Parameterization Suites

- Community Earth System Model
- Atmospheric component
- Goals: Simulate and Predict the Earth System
  - Developmental model: enable science
  - We can still break things
- Current status: releasing a model for CMIP6
  - CESM2, CAM6 is the atmosphere component
- Ongoing development: “across scales”
  - Pushing to work across weather to climate
  - Need to develop parameterizations across scales
  - Also: COUPLE parameterizations (sub-grid scale important)

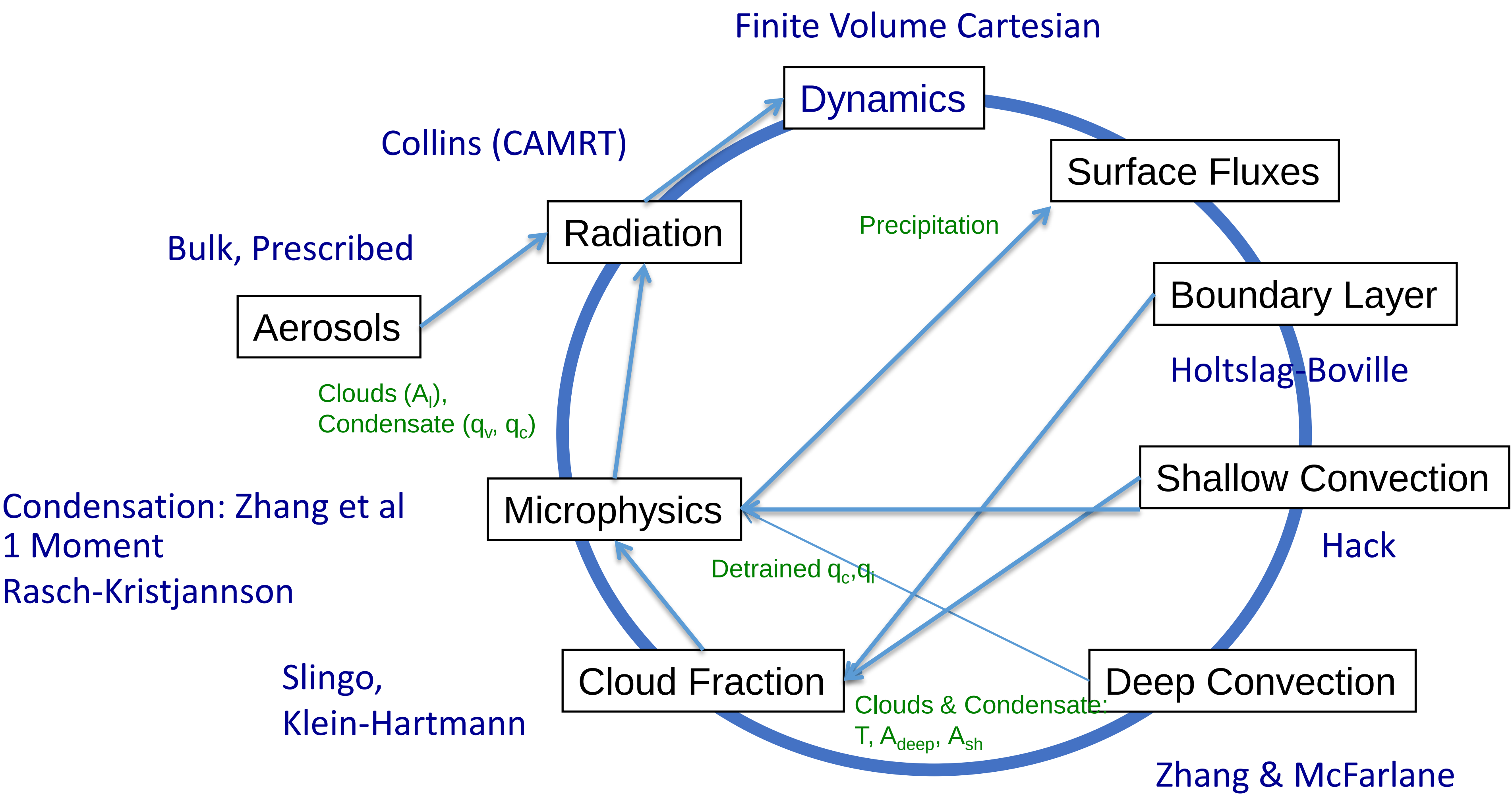
The CAM family

Model	CAM3 CCSM3	CAM4 CCSM4	CAM5 (CAM5.3) CESM1.0 (CESM1.2)	CAM6 CESM2
Release	**Jun 2004**	**Apr 2010**	**Jun 2010 (Nov 2012)**	**January 2017**
Microphysics	Rasch-Kristjansson (1998)	Rasch-Kristjansson (1998)	Morrison-Gettelman (2008)	Gettelman-Morrison (2015) MG2
Deep Convection	Zhang-McFarlane (1995)	ZM, Neale et al. (2008)	ZM, Neale et al. (2008)	ZM, Neale et al. (2008)
PBL	Holtslag-Boville (1993)	Holtslag-Boville (1993)	Bretherton et al (2009)	CLUBB: Bogenschutz et al 2013
Shallow Convection	Hack (1994)	Hack (1994)	Park et al. (2009)	
Macrophysics	Rasch-Kristjansson (1998)	Rasch-Kristjansson (1998)	Park et al. (2011)	
Radiation	Collins et al. (2001)	Collins et al. (2001)	Iacono et al. (2008)	Iacono et al. (2008)
Aerosols	Bulk Aerosol Model	Bulk Aerosol Model BAM	3 MODE Modal Aerosol Model Ghan et al. (2011)	4 MODE Modal Aerosol Model Ghan et al. (2011)
Dynamics	Spectral	Finite Volume	Finite Volume	Finite Volume//Spectral Element (High Res)

= New parameterization/dynamics

Community Atmosphere Model (CAM4)

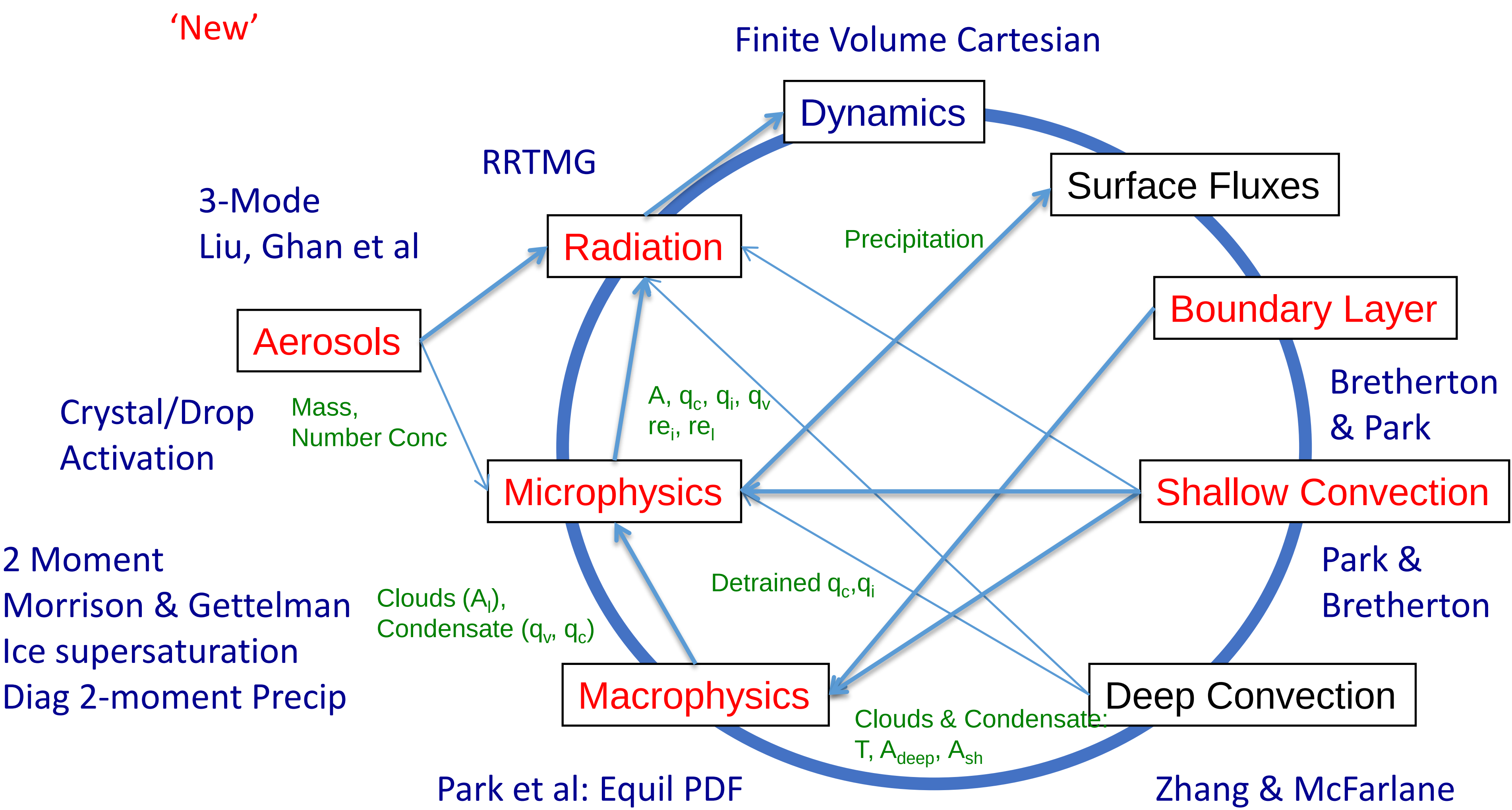
CCSM4: IPCC AR5 version (Neale et al 2010)



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Community Atmosphere Model (CAM5)

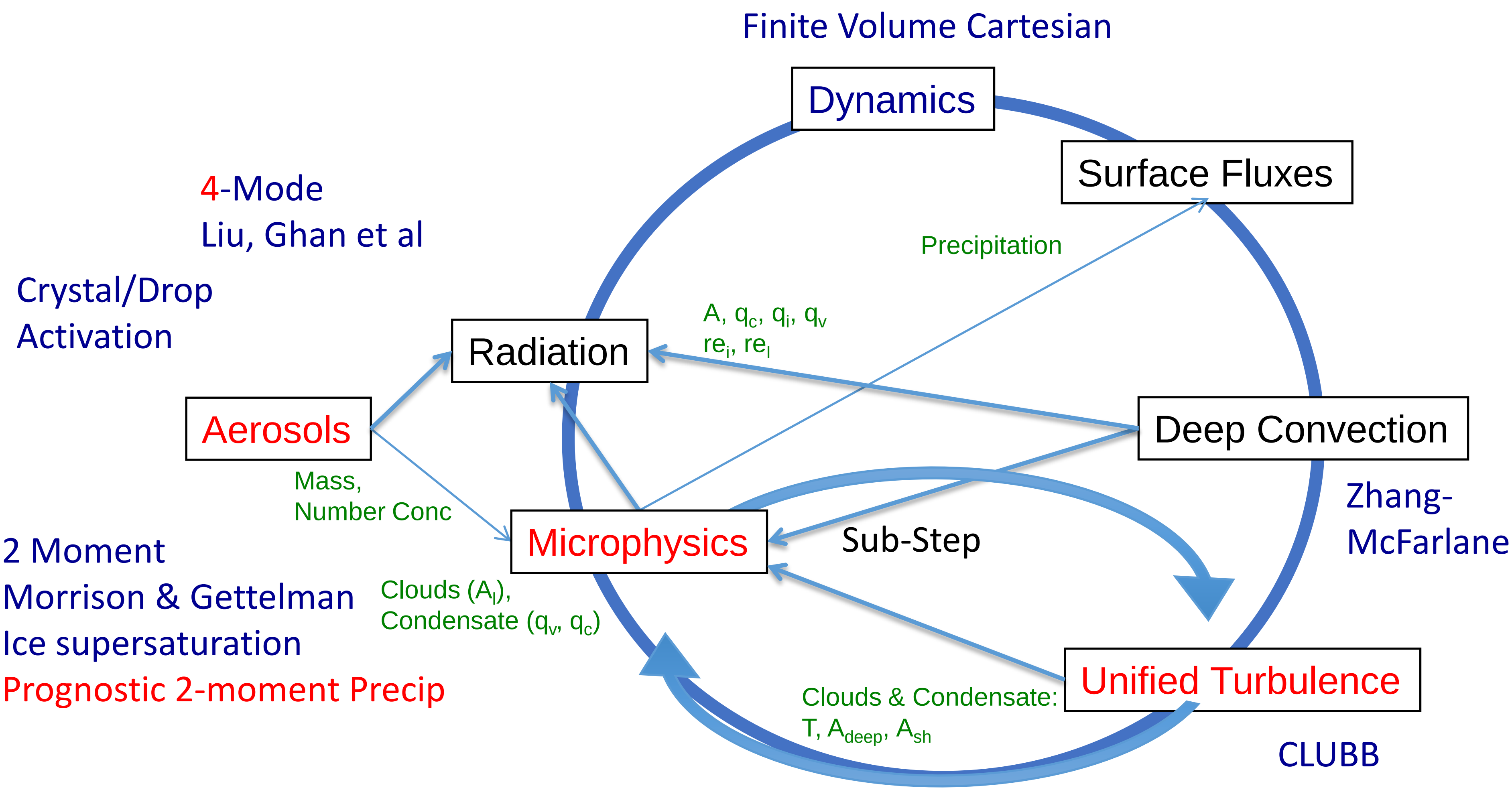
CAM5.1-5.3: IPCC AR5 version (Neale et al 2010)



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Community Atmosphere Model (CAM6)

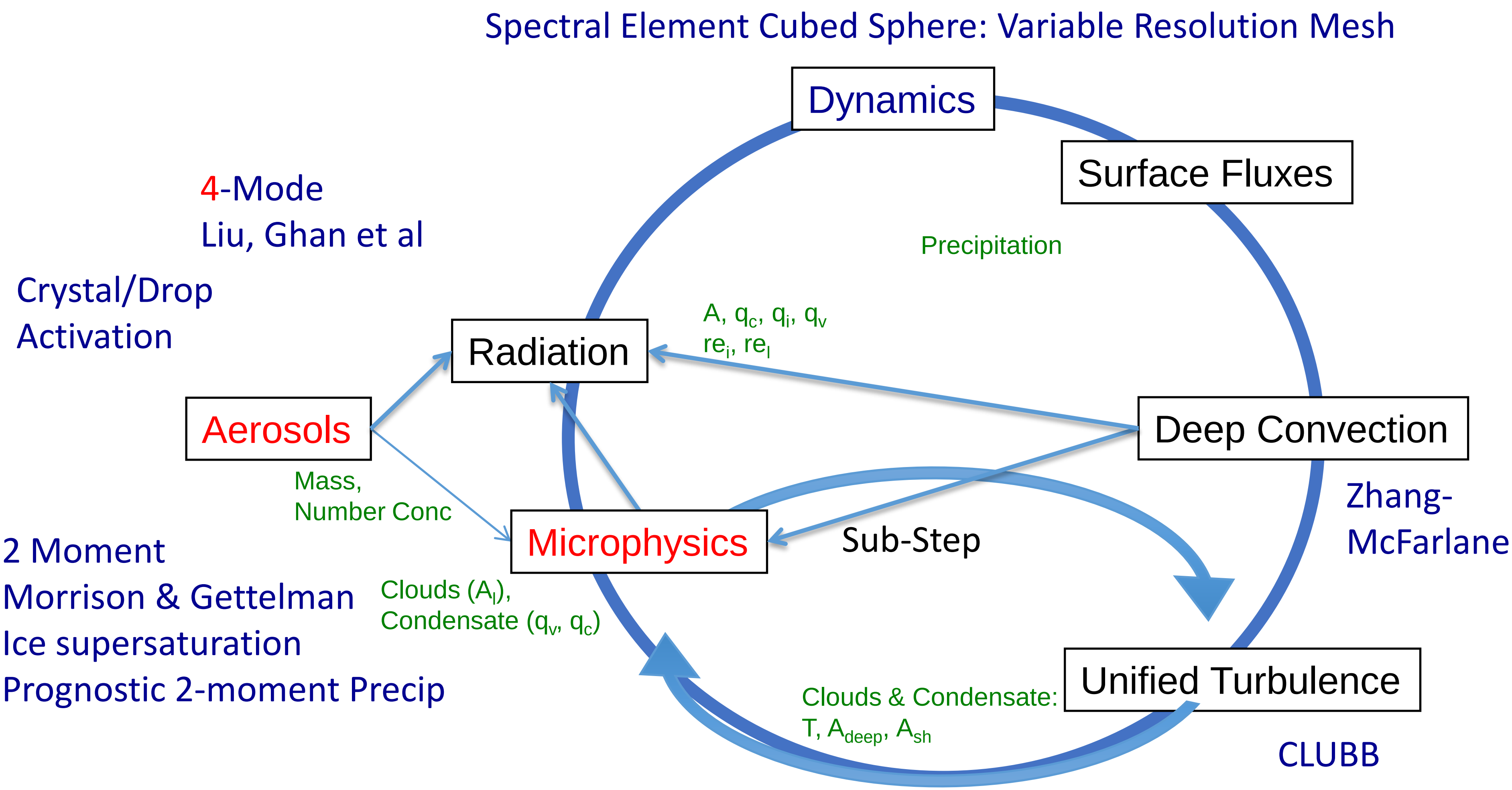
CMIP6 model



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Community Atmosphere Model (0.25°)

Working on this as an option



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

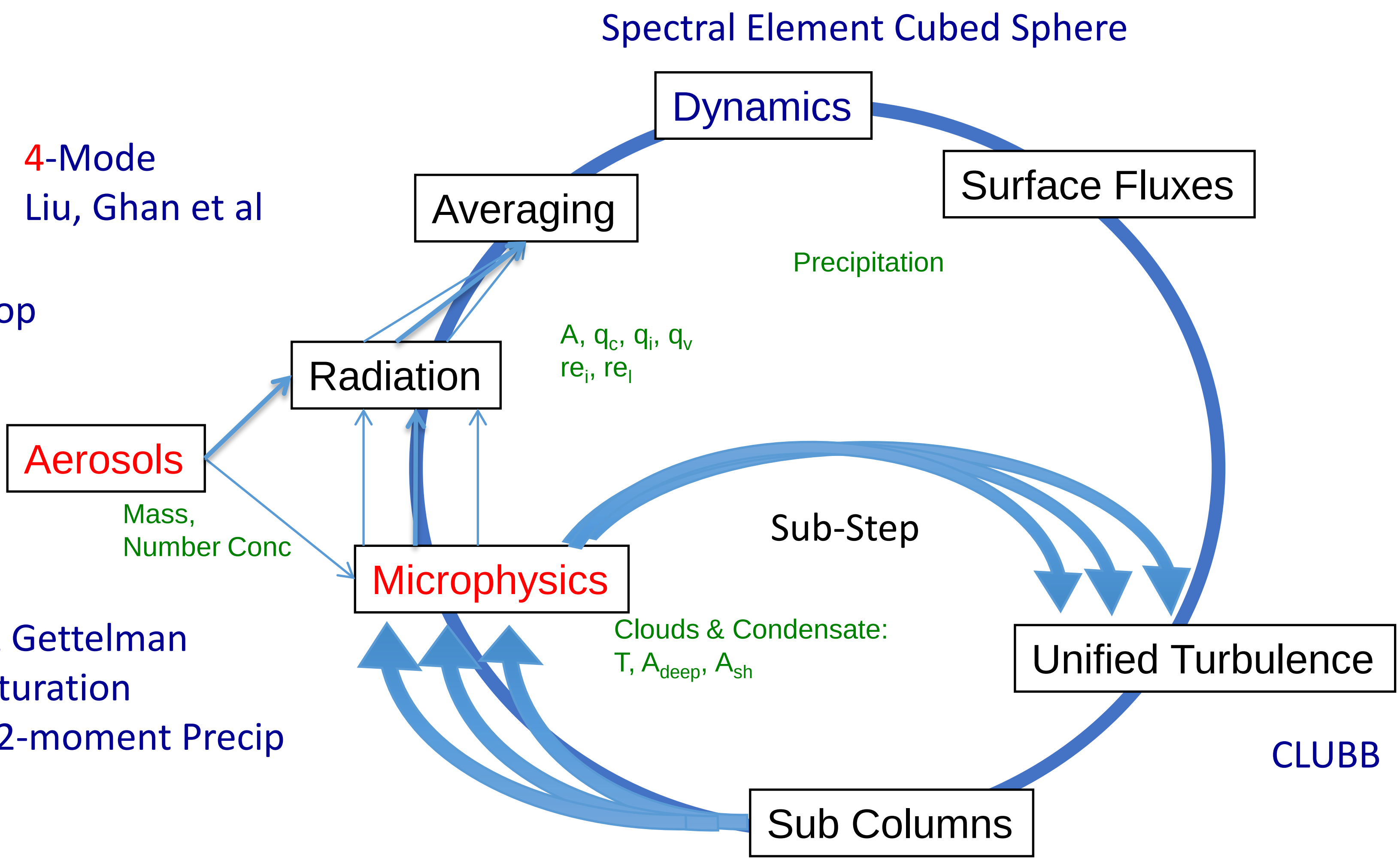
Community Atmosphere Model (CAM6.X)

Now in development: Sub-columns

4-Mode
Liu, Ghan et al

Crystal/Drop
Activation

2 Moment
Morrison & Gettelman
Ice supersaturation
Prognostic 2-moment Precip

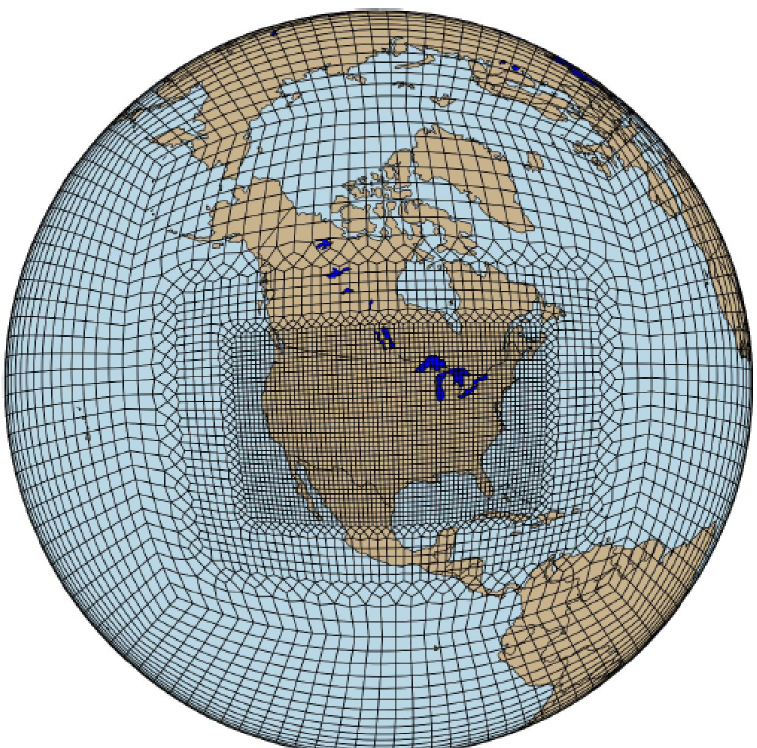


A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Regional Climate modeling

Critical for testing parameterizations

- Regional Climate Framework
- Refine over narrow region, or whole ocean basin



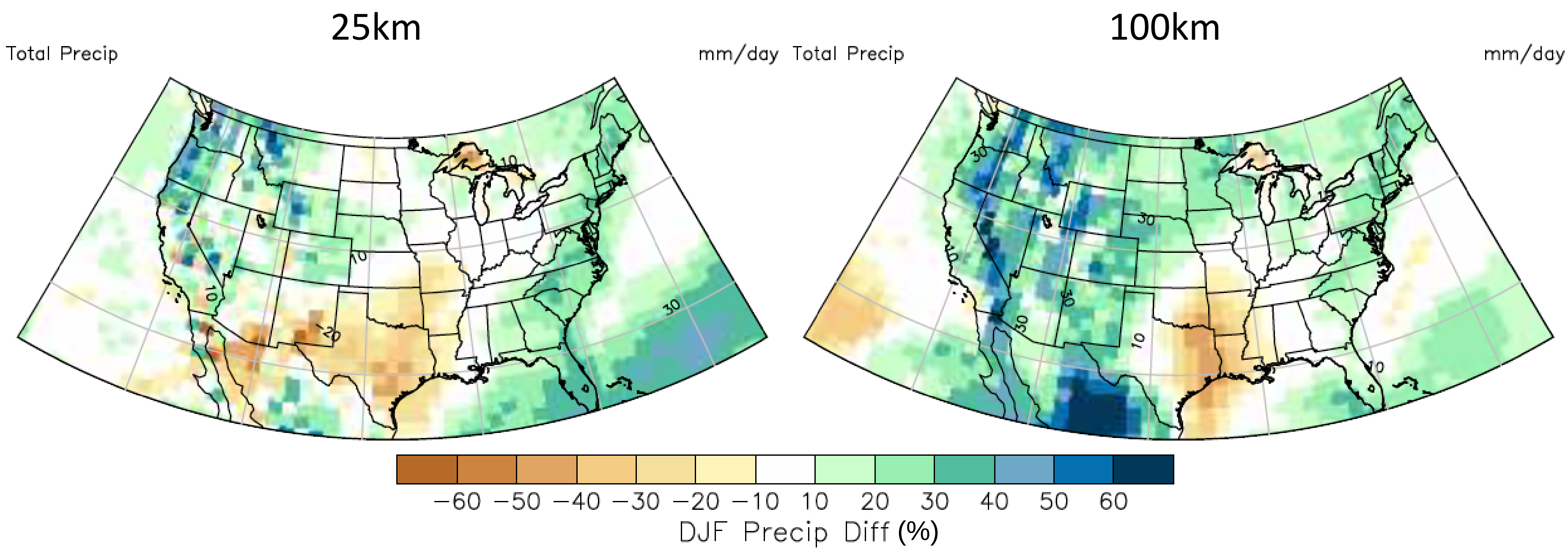
Dynamics seems to work.
Testing whether the physics works now.
Baseline: Coterminous United States (CONUS)
Also: tools to build refinement for anywhere.

100km → 12km (hydrostatic)
100km→ 3km (non-hydrostatic)

CESM: High resolution Mesh

Biases v. ERA-I DJF Precipitation Climatology

Reduced biases at high resolution, especially orographic precip



Re-gridded to 100km

Philosophy of Interactions

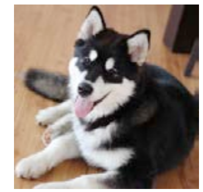
- Consistency across/between parameterizations is key
  - Cannot just pick from a buffet
- Couple parameterizations effectively
  - ‘simple’ parameterizations
  - ‘fewer’ parameterizations (less complex linkages)
  - Optimize parameterizations together
- Flexibility for sub-grid variability
  - What is ‘sub-grid’ may change with resolution
  - Make sure representations are valid across scales
- Build in capability to test across scales from weather to climate
  - Climate felt through weather (need key detailed processes)
  - Weather should obey conservation
  - Unified FRAMEWORK (not necessarily a single model)

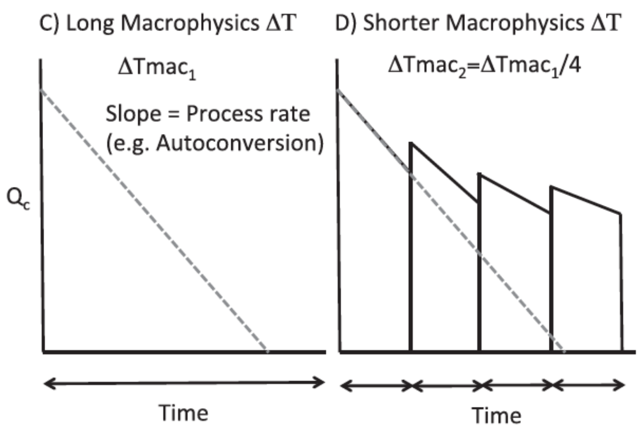
How not to build a climate model

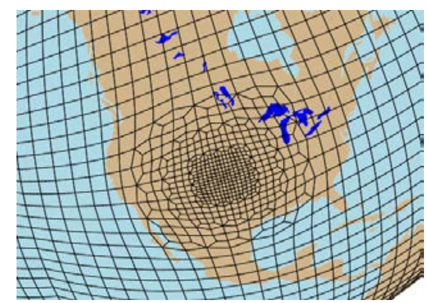
- Two paths possible (in parallel)
  - *Operational:* reduce current biases in parameterizations
  - *Research:* Target process improvement
    - This will make the model worse
  - Know what the balance is (research v. operations)
- Lessons
  - Define goals and metrics early
  - Complete model infrastructure (software engineering) FIRST
  - Couple early and often (parameterizations and coupled components)
    - Putting everything together at the end rarely goes well
  - Need understanding of the sensitivity of processes/components
  - Have a ‘plan B’: ideally incremental steps.
    - But that makes fundamental advances harder
  - Community modeling is a strength: modeling is too big for one group

Summary/Conclusions

- "All models are wrong, but some are useful"
- Not just each parameterization,
- But their interactions are key
- Numerics are important







- Multi-scale models are a promising goal/testbed
- Model development depends on strategic vision