Physics Parameterizations in Global Atmospheric Models

Intro to CAM-CLUBB Tutorial 2019

NCAR

Monday June 10th

Outline

- What are “AGCM Physics”?
- Resolution, subgrid variability, nonlinearity
- Basic design of parameterizations
- Future directions

Equations of Motion – explicitly resolved dynamics

Where do the "physics" appear?

$$d\overline{\mathbf{V}}/dt + fk \times \overline{\mathbf{V}} + \nabla\overline{\phi} = \mathbf{F},$$ *(horizontal momentum)*

$$d\overline{T}/dt - \kappa\overline{T}\omega/p = Q/c_p,$$ *(thermodynamic energy)*

$$\nabla \cdot \overline{\mathbf{V}} + \partial\overline{\omega}/\partial p = 0,$$ *(mass continuity)*

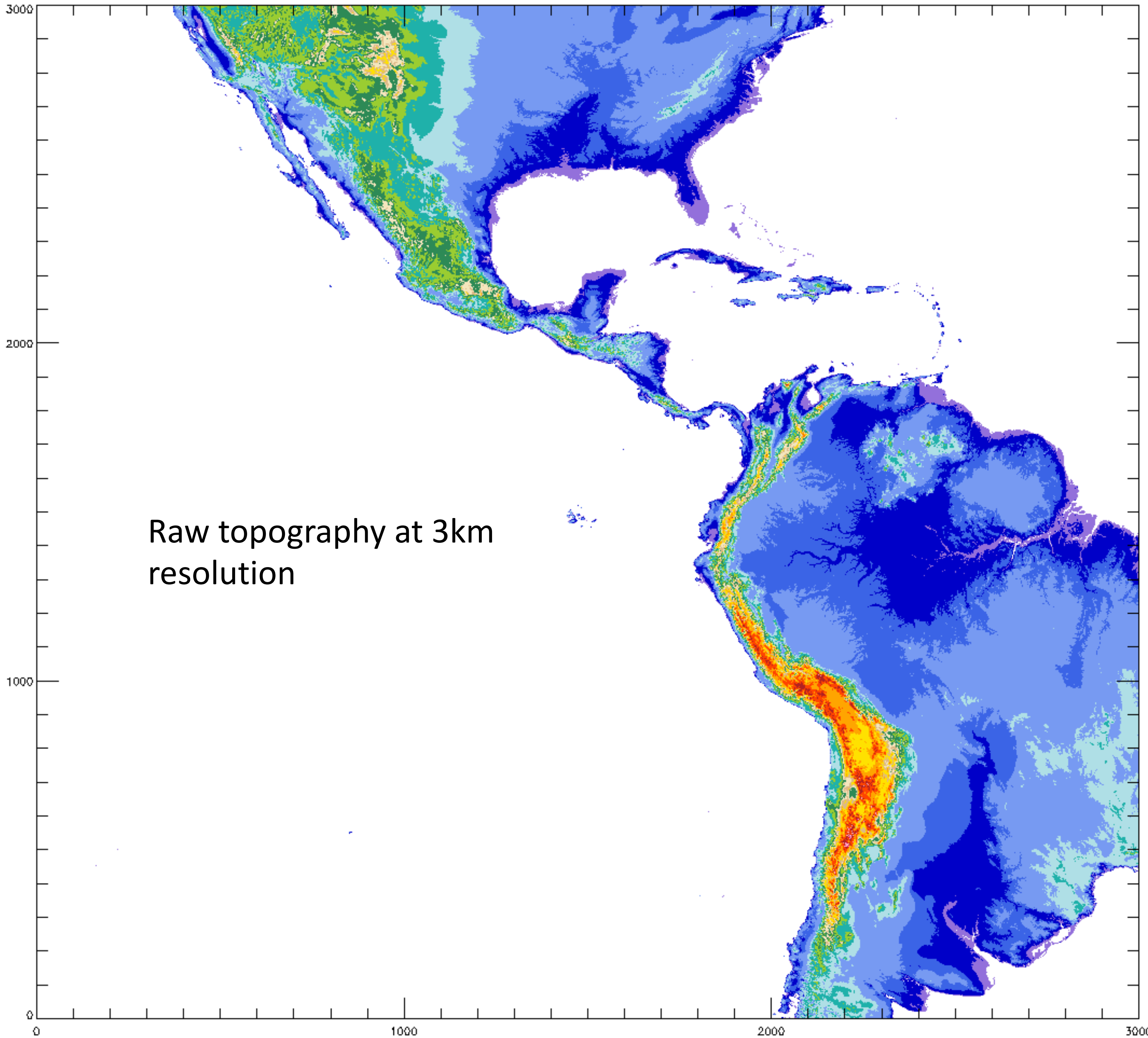
$$\partial\overline{\phi}/\partial p + R\overline{T}/p = 0,$$ *(hydrostatic equilibrium)*

$$d\overline{q}/dt = S_q.$$ *(water vapor mass continuity)*

$dq_{\{l,i,r,\ldots\}}/dt =$ **F_{QV}, F_{QL}, F_{QI} …? *(water substance evolution equations, chemistry …)***

What are the “physics” trying to represent?

Unresolved motions, sub-grid variability, …. photons … chemistry/microphysics ….



Raw topography at 3km resolution
3000
2000
1000
0
0
1000
2000
3000

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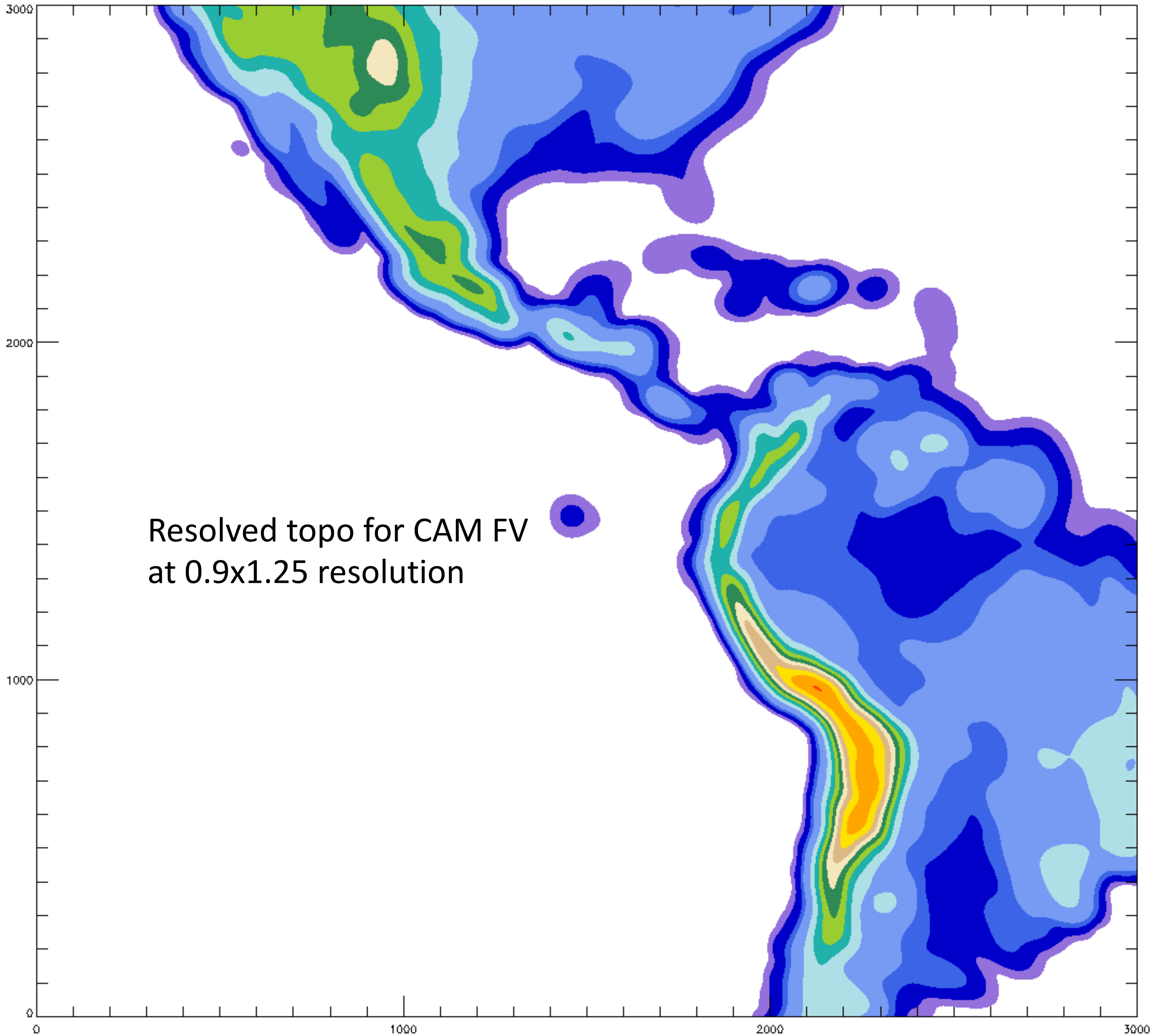
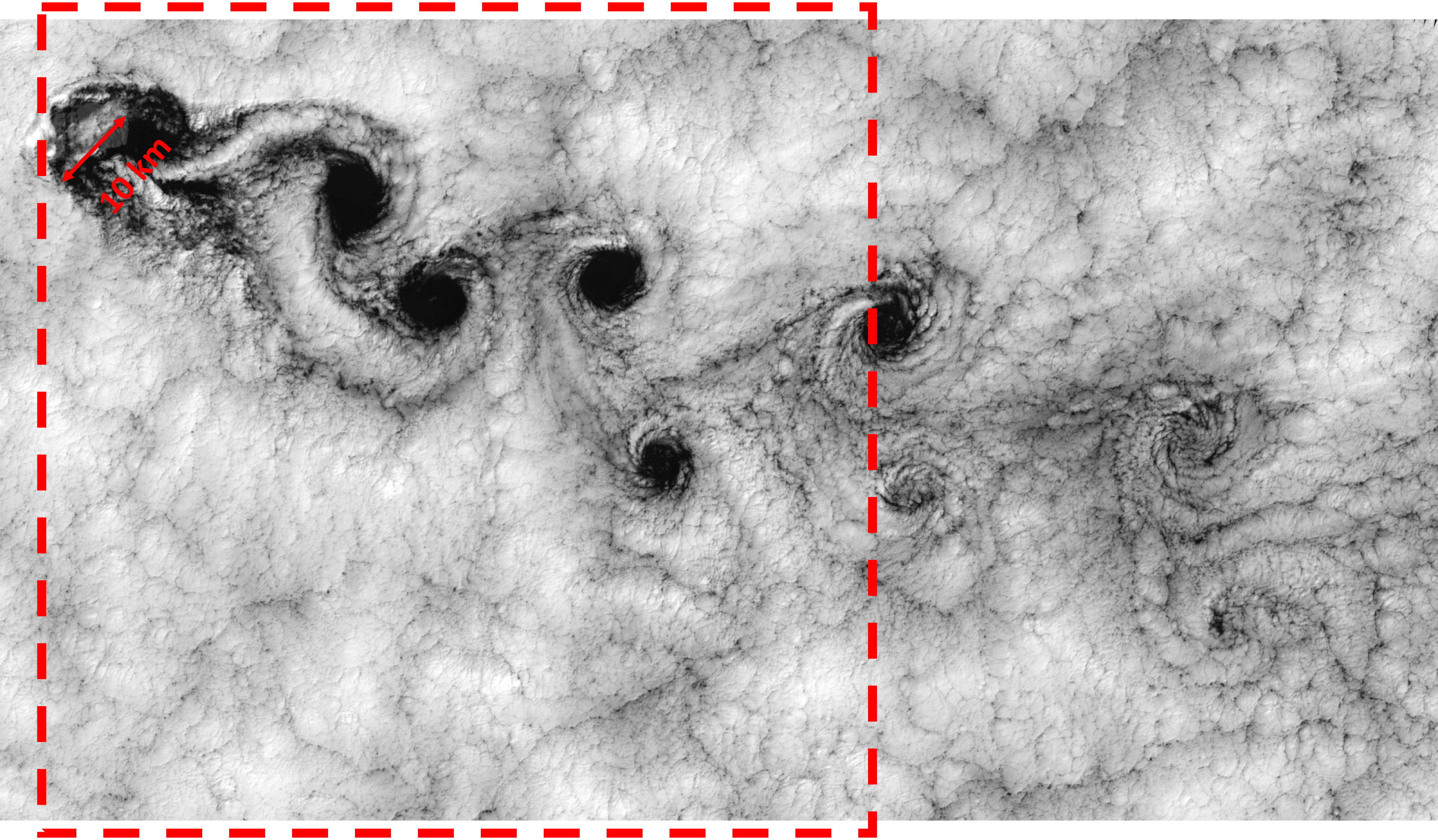


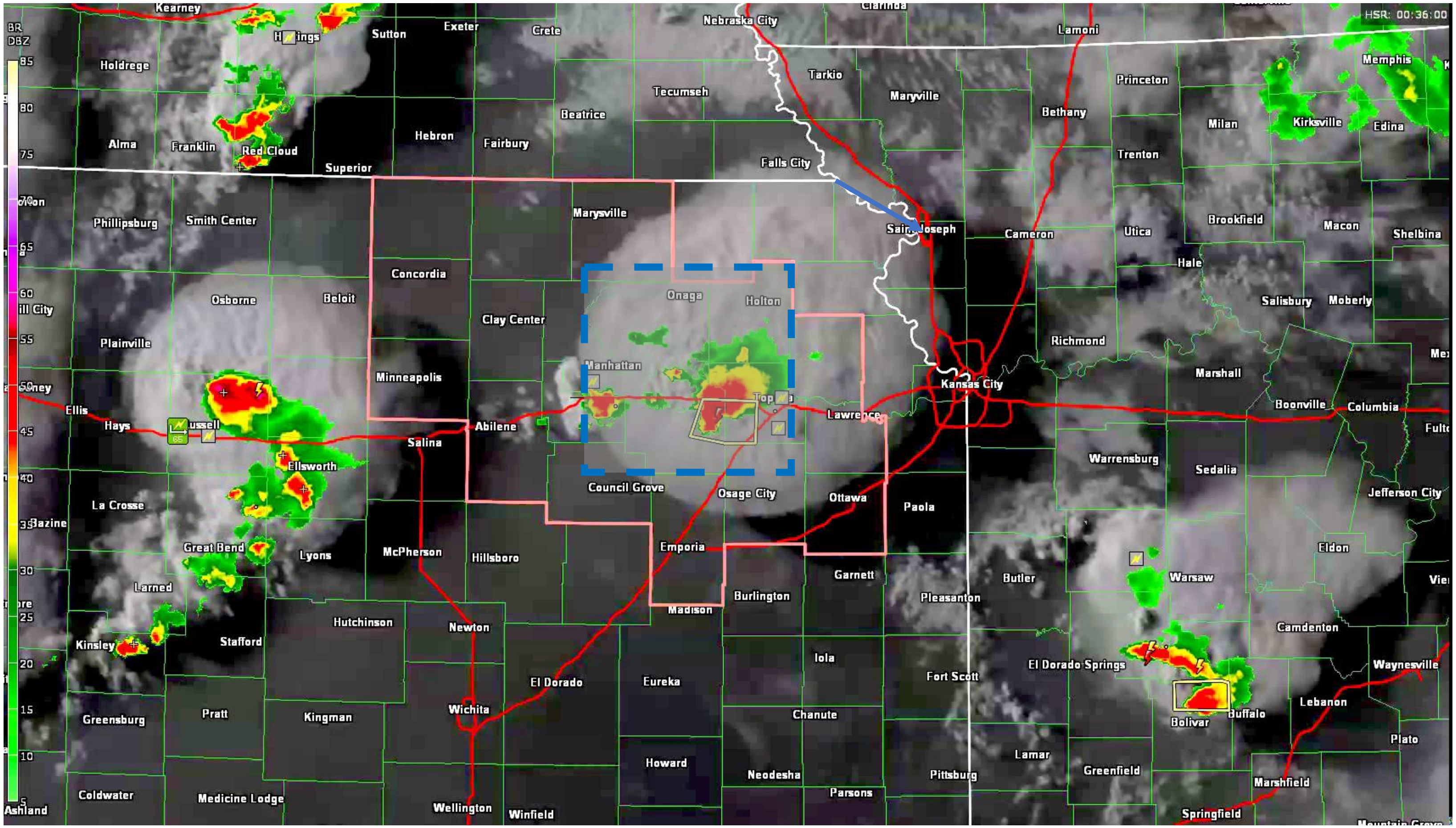
Resolved topo for CAM FV
at 0.9x1.25 resolution

Boundary layer clouds



Alejandro Selkirk Island (33S 80W)

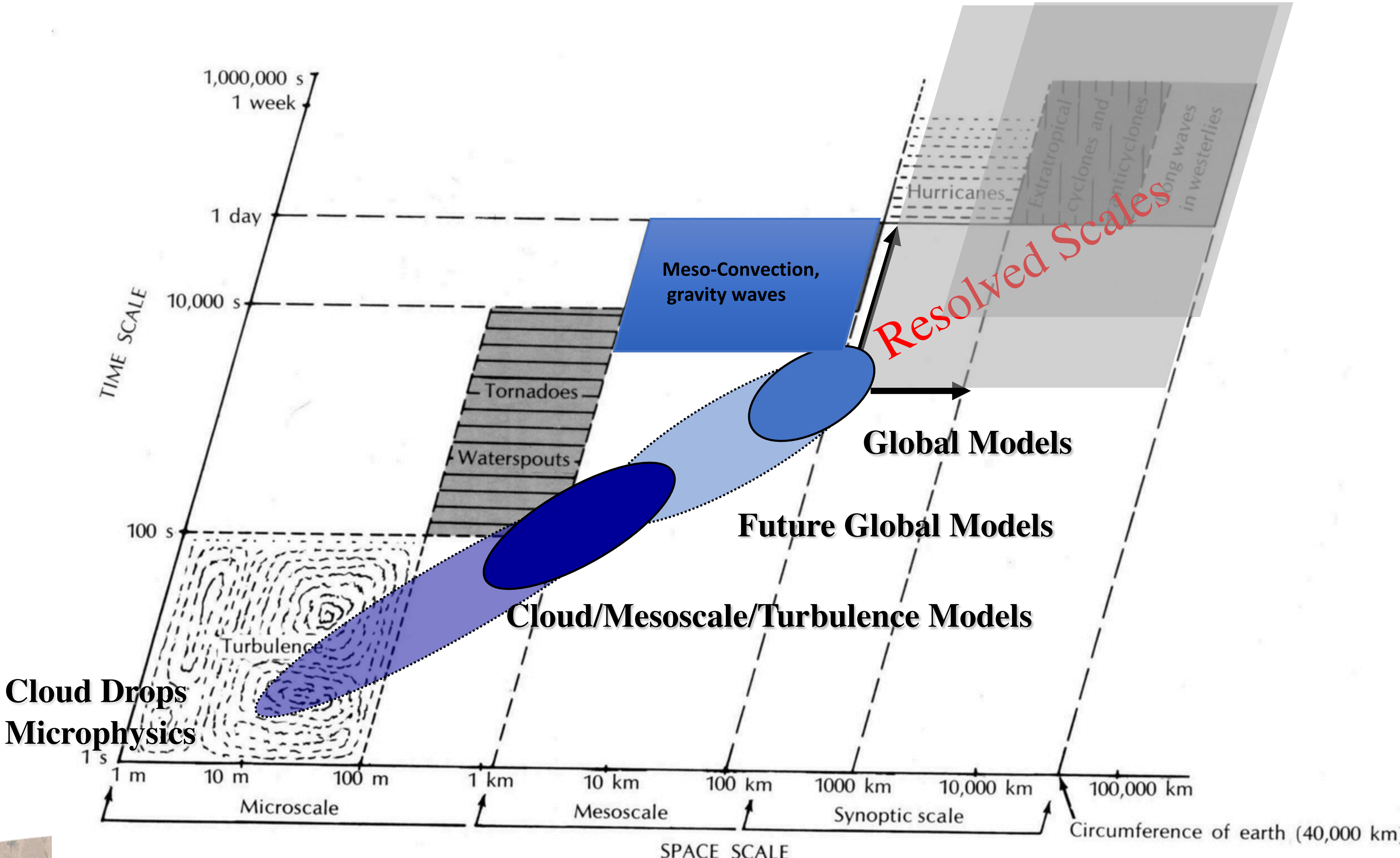
Deep Convection



July 15, 2015

Scales of Atmospheric Processes

Resolved processes vs parameterized



Atmospheric models with large grid boxes miss a lot of interesting stuff

….

Does it matter??

Nonlinearity

5 Values of "*x*" = 1,1,1,2,10

$$M(p) = \left[\frac{1}{5}\sum x^p\right]^{\frac{1}{p}}$$

p=1

M(p)=3.00000

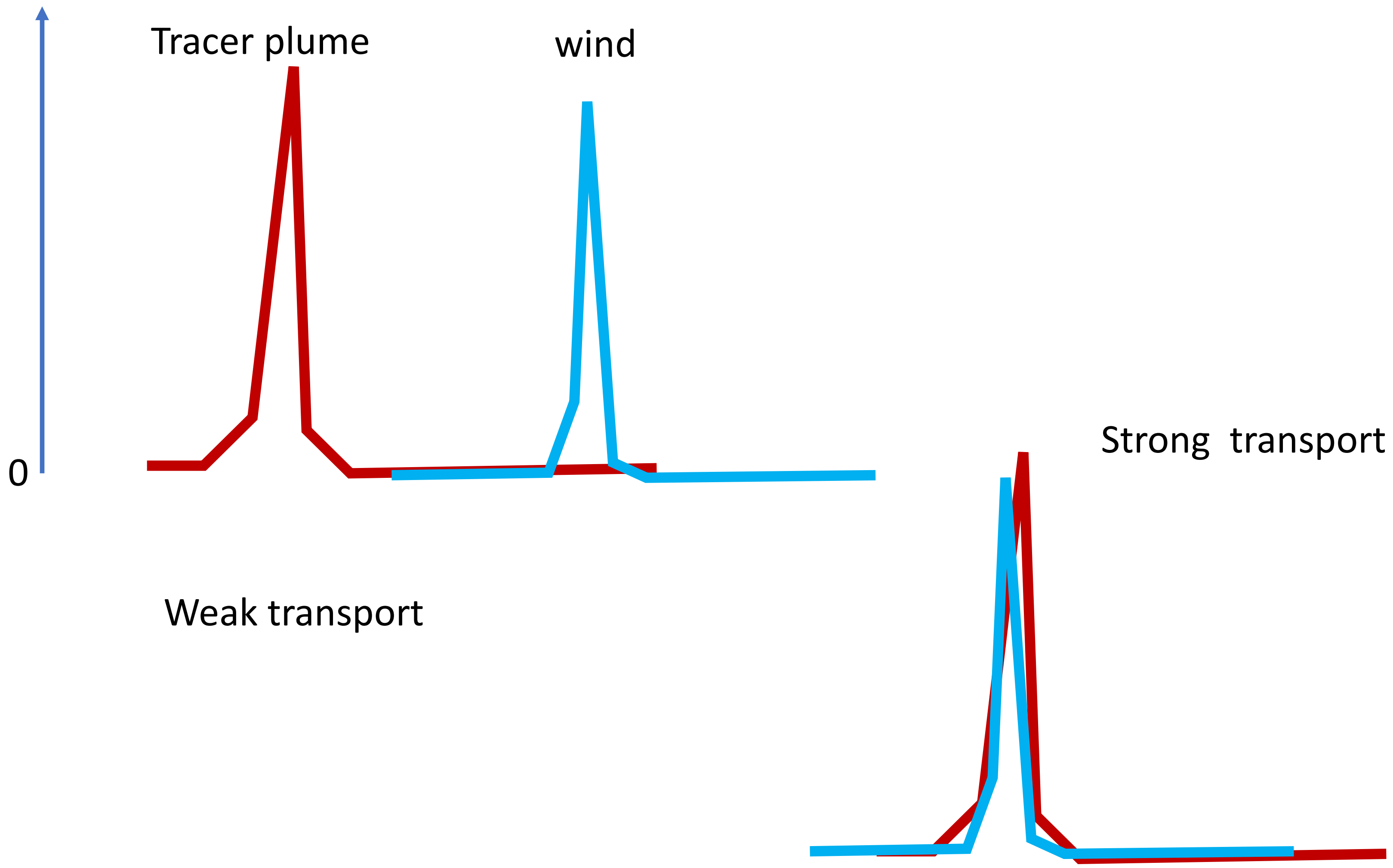
p=2

M(p)=4.62601

p=10

M(p)=8.51340

Nonlinearity



How do nonlinearities arise?

e.g., Cloud microphysics:

Autoconversion of cloud water to rain

$$P_{l->r} = kq_l{}^a N_l{}^b$$

a ranges from 2 to 4;
b from around -1 to -2

Condensation at RH=1

How do nonlinearities arise?

Fluxes:

$$\partial_t(\rho s) + \partial_x(\rho u s) + \partial_y(\rho v s) + \partial_z(\rho w s) = P_s$$

$$\partial_t(\rho \bar{s}) + \partial_x(\rho \bar{u}\bar{s}) + \partial_y(\rho \bar{v}\bar{s}) + \partial_z(\rho \bar{w}\bar{s}) = \bar{P}_s - \partial_x \rho \overline{u's'} - \partial_y \rho \overline{v's'} - \partial_z \rho \overline{w's'}$$

$\overline{(\ )}$ large−scale horiz. average; $(\ )'$ deviation from avg.

What do parameterizations do?

- Physics schemes - *"parameterizations"* - need to return tendencies as functions of model grid mean variables
- Tendency calculations may include representation of subgrid variability

$$d\overline{\mathbf{V}}/dt + fk \times \overline{\mathbf{V}} + \nabla\overline{\phi} = \mathbf{F}, \qquad \textit{(horizontal momentum)}$$

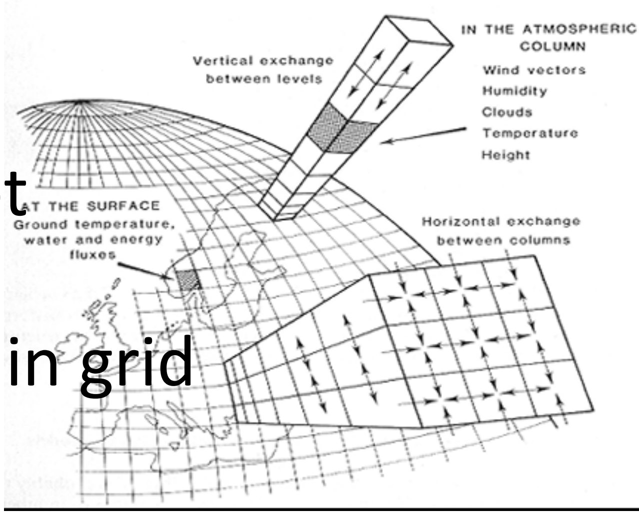
$$d\overline{T}/dt - \kappa\overline{T}\omega/p = Q/c_p, \qquad \textit{(thermodynamic energy)}$$

$$d\overline{q}/dt = S_q. \qquad \textit{(water vapor mass continuity)}$$

Parameterizations
High level design

1. Inputs and effects totally contained within single columns
   - Single grid point structures are believed
2. Most (many common) schemes do not possess a “memory”
3. Assume sufficient space-time volume in grid means for “good” statistics
4. For climate should be mass, momentum and energy conserving (limiters and fixers)

1,2 and 3 begin to cause trouble as resolution increases and time-steps decrease



"Column physics"

Subgrid horizontal fluxes are typically ignored in atmospheric models

$$\partial_t(\rho\bar{s}) + \partial_x(\rho\bar{u}\bar{s}) + \partial_y(\rho\bar{v}\bar{s}) + \partial_z(\rho w s) = \bar{P}_s - \partial_x\rho\overline{u's'} - \partial_y\rho\overline{v's'} - \partial_z\rho\overline{w's'}$$

$$\partial_t(\rho\bar{s}) + \partial_x(\rho\bar{u}\bar{s}) + \partial_y(\rho\bar{v}\bar{s}) + \partial_z(\rho w s) = \bar{P}_s - \partial_z\rho\overline{w's'}$$

Column physics don't need to communicate with neighboring grid columns ➔ "embarrassingly parallel"

Physics Parameterizations needed by an AGCM

- Radiation
  - Clear sky (typically no subgrid variability used)
  - Cloudy
- Surface exchanges
- Boundary Layer Turbulence
- Shallow convection
- Cloud "macrophysics"
- Deep Convection
- Cloud microphysics
- PBL form drag
- Gravity wave drag

Physics Parameterizations in CAM6

- Radiation RRTMG
  - Clear sky (typically no subgrid variability used)
  - Cloudy
- Surface exchanges Similarity theory (Monin-Obukhov …)
- Boundary Layer Turbulence
- Shallow convection
- Cloud "macrophysics"

CLUBB prognostic moments

- Deep Convection Zhang & McFarlane mass flux scheme
- Cloud microphysics Morrison Gettelman 2-moment
- PBL form drag Beljaars et al neutral shear flow over obstacles
- Gravity wave drag Lindzen-type schemes for various sources
- Complex prognostic aerosol model

How are parameterizations built?

- Basic physics
- Empirical formulations from observations or high-resolution calculations (e.g. LES, CRMs)
- Some simple conceptual model – “cartoon”

Parameterizations

How do they couple to other parts of model?

Process splitting versus ***time splitting***

Process splitting:

- All parameterizations work on same state. Provide tendencies for unified update

Time splitting

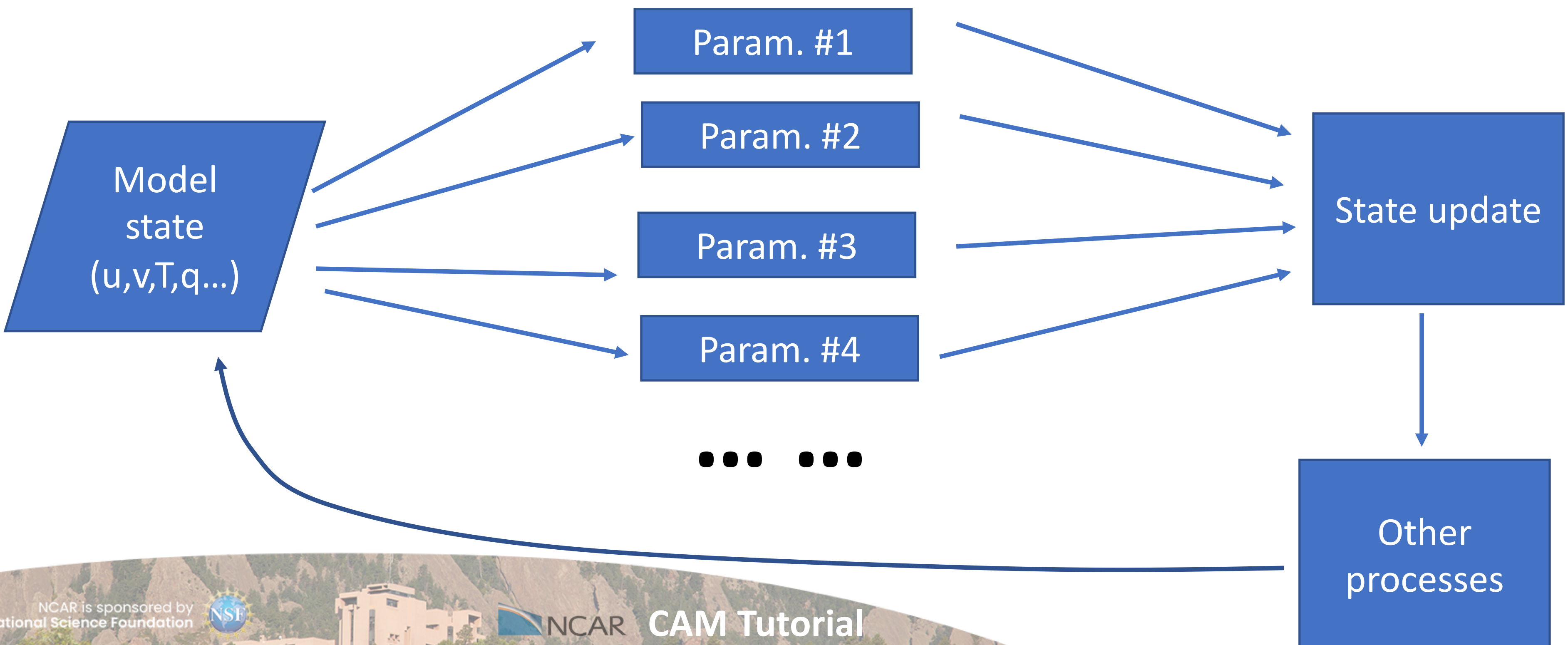
- Parameterizations update state as they work and pass updated state to next param.

Parameterizations

How do they couple to other parts of model?

Process splitting:

- All parameterizations work on same state. Provide tendencies for unified update

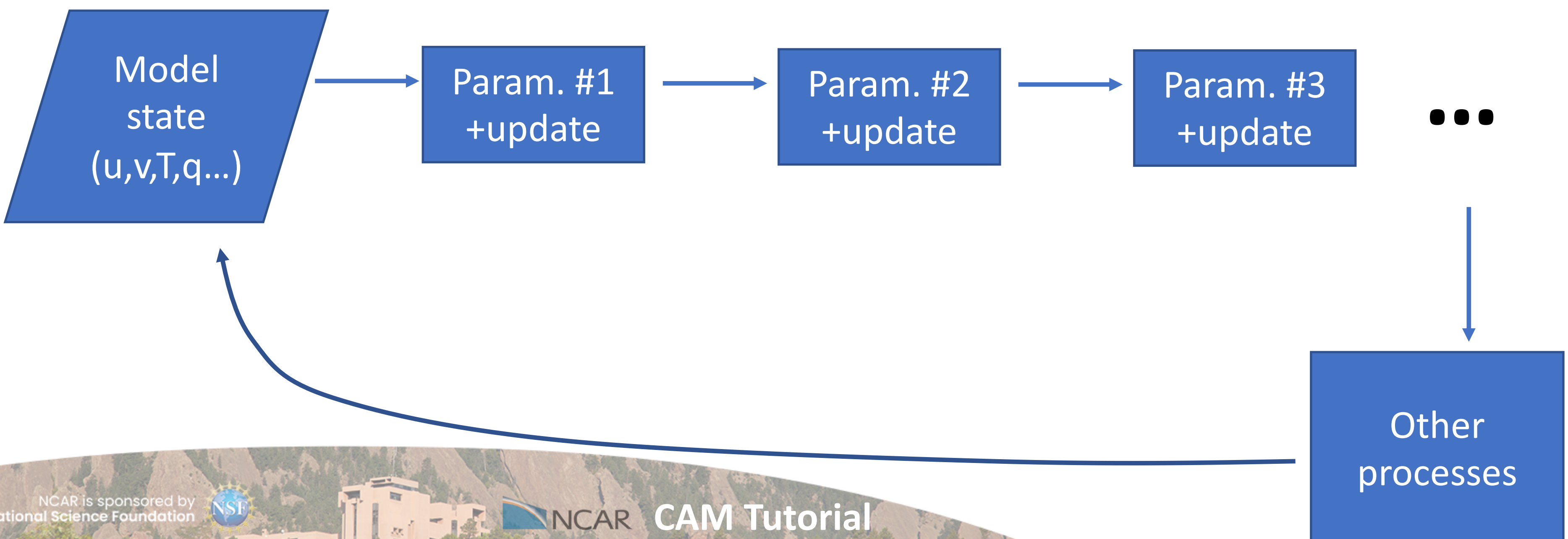


Parameterizations

How do they couple to other parts of model?

Time splitting (currently used in CAM)

- Parameterizations update state as they work and pass updated state to next param.



Future Directions for Physics in Models?

What do we need to consider?

As grid-sizes and time steps decrease, parameterizations may need to communicate across space and time

As grid-sizes and time steps decrease, resolved scales may not contain enough information to close parameterizations

- Stochastic elements?
- Life-cycles of processes?

At any resolution, better sub-grid representations are needed

- Subcolumns?

Future Directions for Physics in Models?

Science insurgents plot a climate model driven by artificial intelligence

By [Paul Voosen]Jul. 26, 2018 , 2:00 PM

http://www.sciencemag.org/news/2018/07/science-insurgents-plot-climate-model-driven-artificial-intelligence