

**THE CONVERGENCE PROBLEM OF MODEL PHYSICS  
AND  
QUASI-3D SUPER-PARAMETERIZATION**

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## HISTORICAL ASSESSMENT

Arakawa, A., 2003: The Cumulus Parameterization Problem:  
Past, Present, Future  
(To be submitted)

- A number of cumulus parameterization schemes have been constructed *using quite different rationale*.
- Yet GCMs with these schemes can produce *comparable* results.

*Thus cumulus parameterization  
did not appear to be a too demanding problem.*

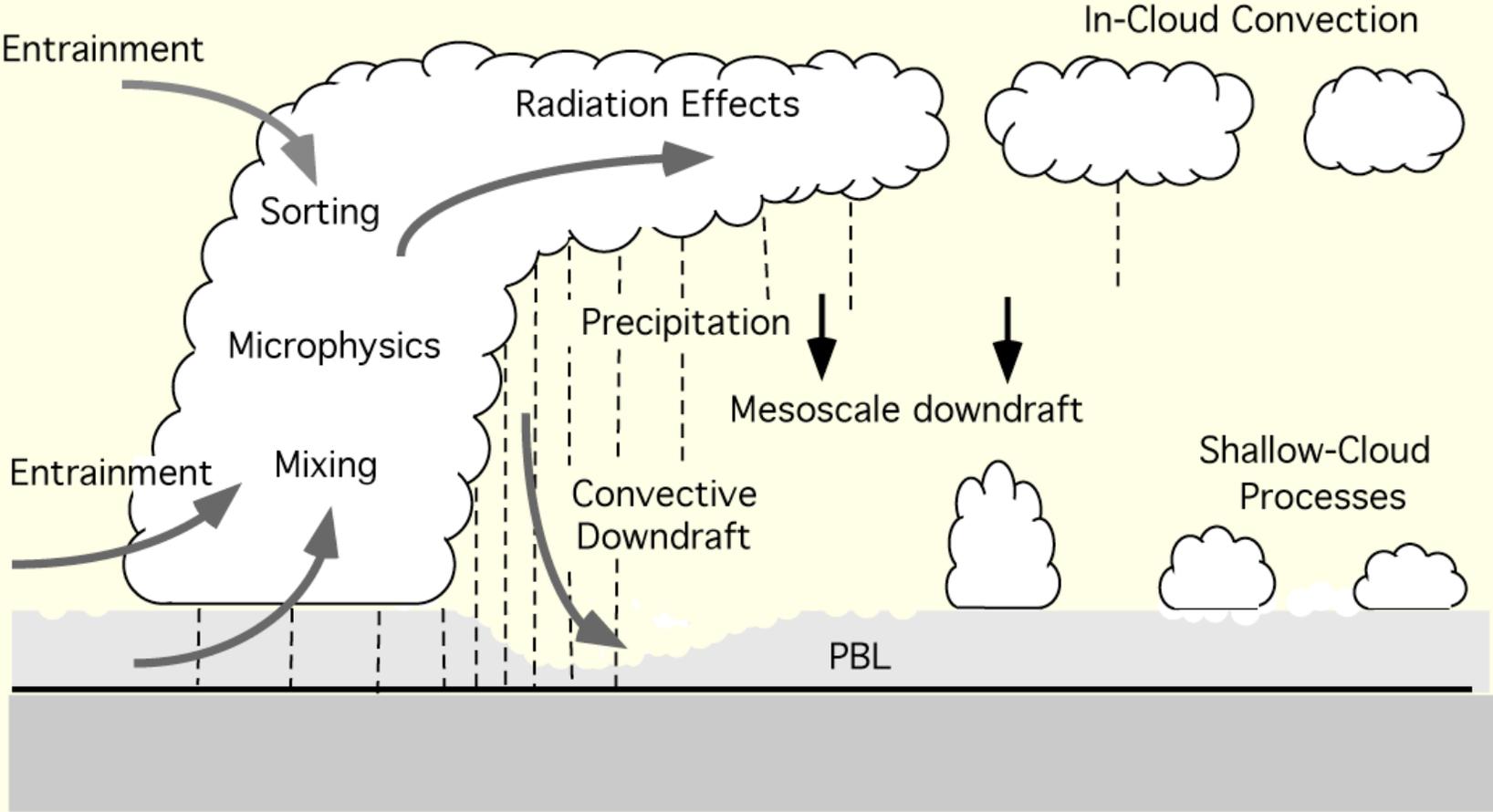
## HISTORICAL ASSESSMENT

### CONTINUED

- All surviving cumulus parameterizations can produce a negative feedback to large-scale destabilization.
- When SST is fixed, this negative feedback tends to hide model deficiencies and model differences.

*We cannot rely on this kind of "luck"  
in future climate models.*

# UNCERTAINTIES IN FORMULATING CLOUD AND ASSOCIATED PROCESSES



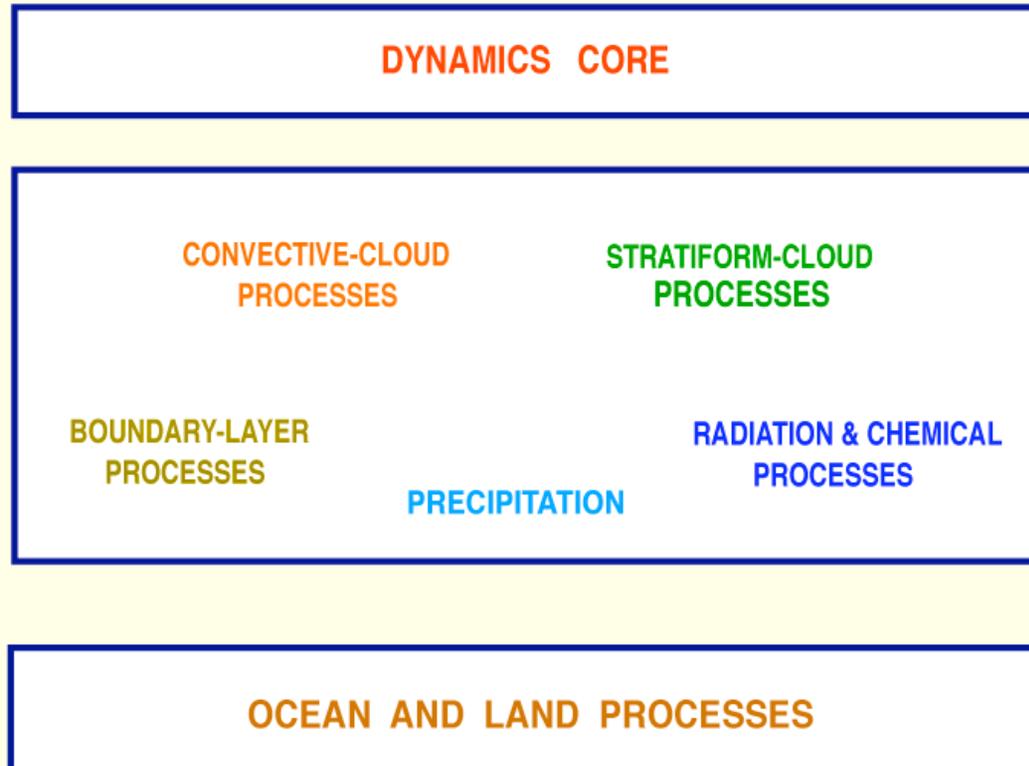
**A PRACTICAL PROBLEM  
IN CONVENTIONAL MODEL PHYSICS**

The lack of an appropriate framework,  
such as a unified cloud-system model,  
for implementing detailed formulations of these processes

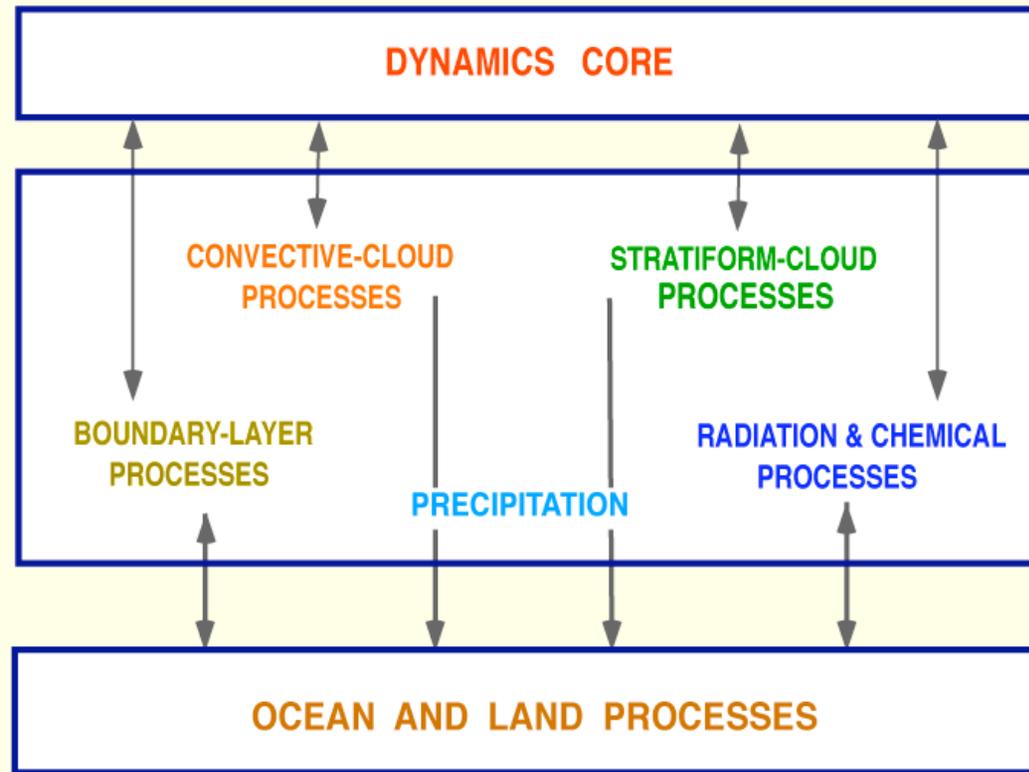
*This involves even conceptual problems.*

# **MAJOR CONCEPTUAL PROBLEMS IN CONVENTIONAL MODEL PHYSICS**

1. Artificial Separation of Processes
2. Artificial Separation of Scales

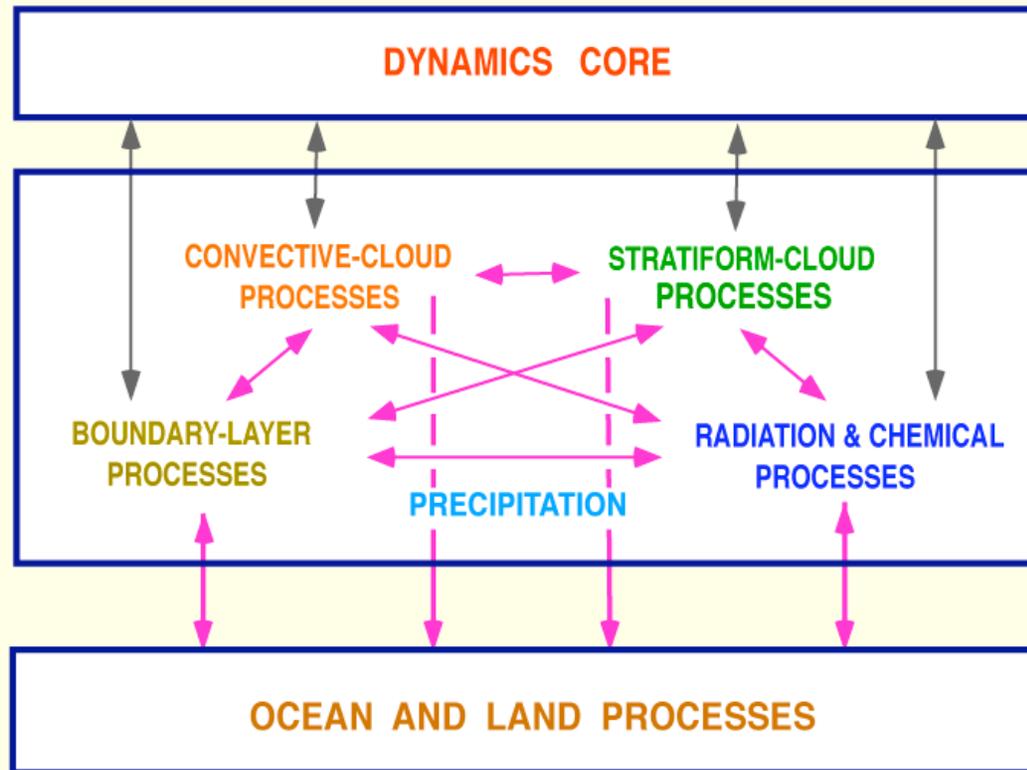


*In the past, our modeling effort has been spent mainly on coupling these physical processes with the dynamics core more or less independently from the others.*



*This resulted in a modular structure, in which different physical processes interact mainly through the time evolution of large-scale variables (and surface conditions).*

# DIRECT INTERACTIONS BETWEEN PHYSICAL PROCESSES INVOLVING SMALL SCALES:



# DIRECT INTERACTIONS BETWEEN PHYSICAL PROCESSES INVOLVING SMALL SCALES

## Examples

### Radiation/Cloud Interactions

Effects of fractional cloud cover and partial cloud overlap on radiation

Effects of radiative cooling/heating near cloud-top/cloud-bottom on in-cloud turbulence and convection

### Cloud/PBL Interactions

Effects of PBL horizontal inhomogeneity on low-level clouds

Effects of downdrafts/precipitation on PBL horizontal inhomogeneity

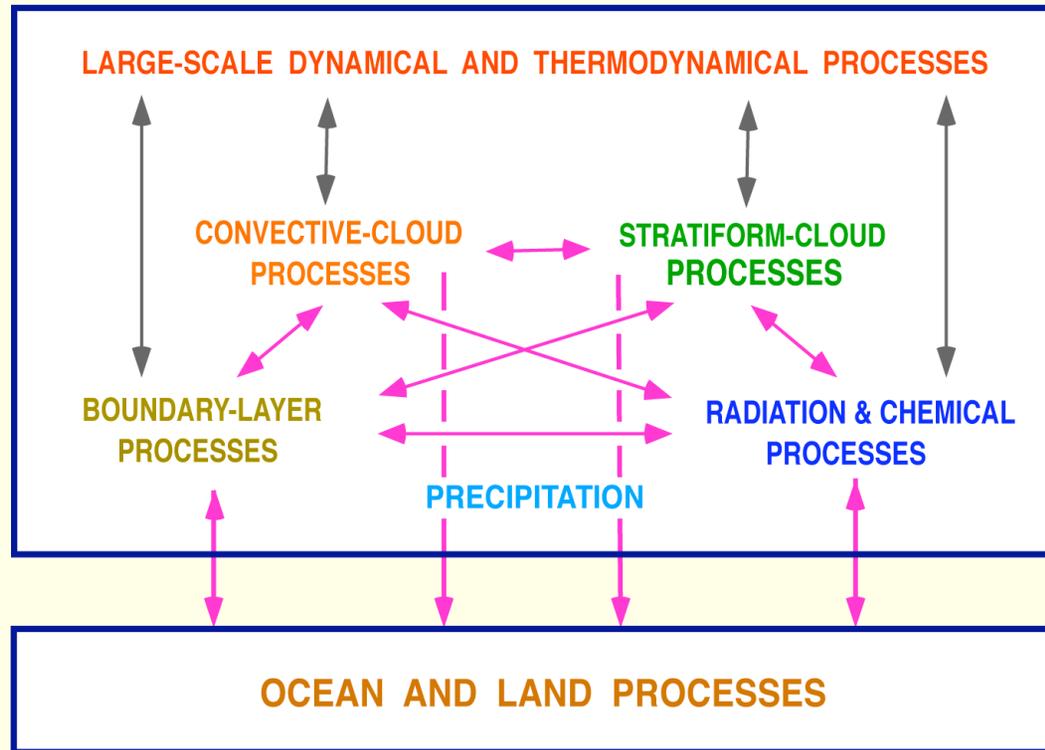
### PBL/Surface Interactions

Effects of surface inhomogeneity due to topography, vegetation, ground wetness, etc., on PBL

Effects of horizontal inhomogeneity of PBL on surface processes

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*One of the future emphases in climate modeling should be on a unified formulation of the entire spectrum of these interactions.*

# MAJOR CONCEPTUAL PROBLEMS IN CONVENTIONAL MODEL PHYSICS

## 2. ARTIFICIAL SEPARATION OF SCALES

Truncation introduced for computational purpose  
separates explicit and implicit scales.

Depending on where truncated, existing models have  
either of the following two kinds of model physics:

### Low-Resolution Model Physics

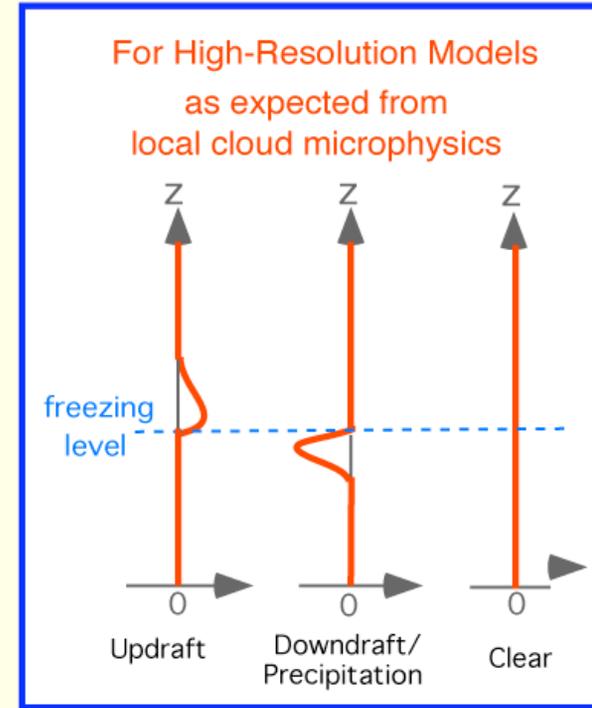
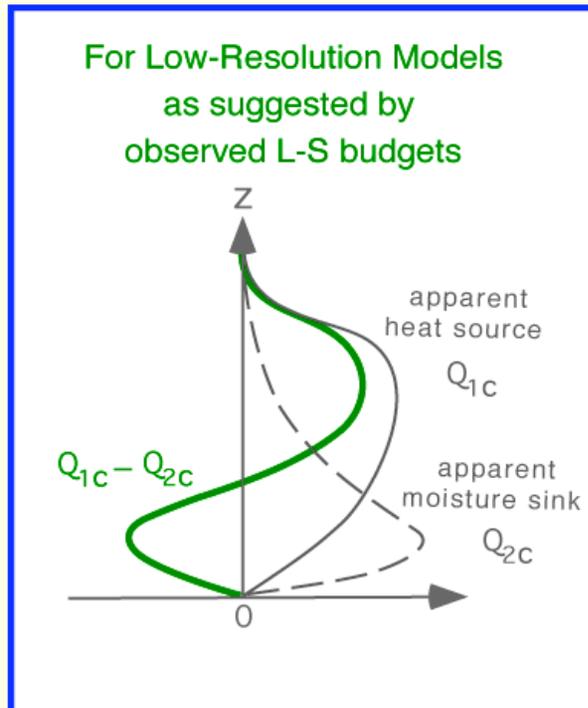
Moist-convective processes  
are parameterized.

### High-Resolution Model Physics

At least a part of  
moist convective processes  
are explicitly represented.

*Each of these is designed and tuned  
for a certain range of resolutions,  
not to formulate physics as a function of resolution  
over a broad spectrum.*

## TYPICAL VERTICAL PROFILES OF MOIST STATIC ENERGY SOURCE DUE TO CONVECTIVE CLOUD PROCESS



*Any space/time/ensemble averages of  
the profiles in the right panel do NOT give  
the profile in the left panel.*

*Conventional parameterizations  
do recognize the difference so that  
they are basically on the right track;  
but they are not scale-dependent.*

## THE CONVERGENCE PROBLEM OF MODEL PHYSICS

Justification of a discrete model relies on the hope that its solution converges to the solution of the original system as the resolution is refined.

The convergence problem for model physics is different from the standard convergence problem in numerical analysis since the governing equation is *modified rather than approximated*.

**"REAL" CLOUD-MICROPHYSICAL SOURCE  
VS.  
"REQUIRED" CLOUD-MICROPHYSICAL SOURCE  
FOR LOW-RESOLUTION MODELS**

*"required" cloud-microphysical source*

= "real" cloud-microphysical source

implicit components of  
+ advection, turbulence & radiation effects  
*induced by cloud microphysics*

*Thus, "required" cloud-microphysical source  
is more than a time/space/ensemble average of  
"real" cloud-microphysical source.*

## The Resolution Dependency of Model Physics: Illustrations from Nonhydrostatic Model Experiments

(Jung and Arakawa 2003, submitted to JAS)

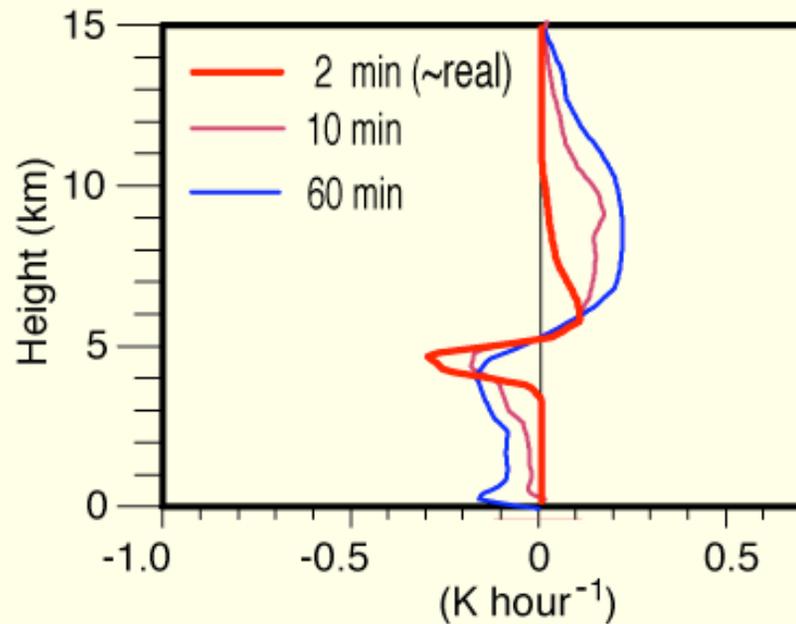
The analysis procedure: Parallel to the diagnosis of "apparent source" from observed large-scale budgets, but more refined.

- APPLICATIONS OF UCLA/U-U/CSU 2D CRM to a variety of idealized tropical conditions.
- CONTROL RUNS with 2-km horizontal resolution and full physics.
- LOW-RESOLUTION RUNS WITH NO CLOUD MICROPHYSICS (or no total physics) over a short time interval from selected realizations in CONTROL.
- From the error of the low-resolution runs, DETERMINATION OF "REQUIRED" CLOUD-MICROPHYSICAL SOURCES for the low-resolution model to become correct as far as resolved scales are concerned.

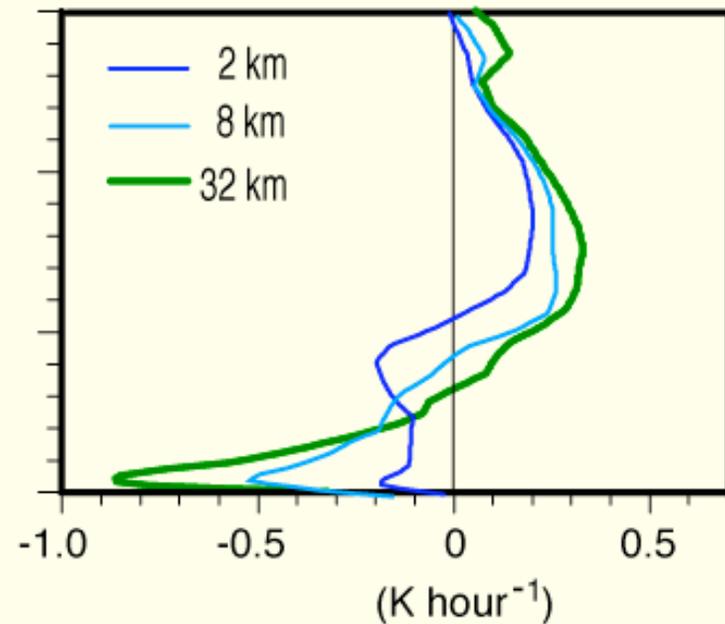
# Domain/Ensemble Average Profiles of "Required" Cloud-Microphysical Source

## Moist Static Energy

Physics time interval dependence  
with 2-km horizontal grid



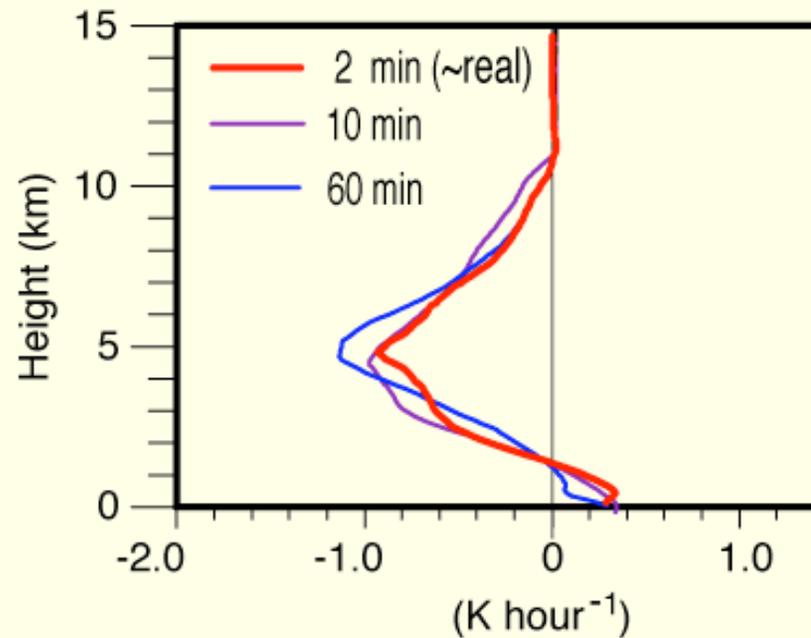
Horizontal resolution dependence  
with 60 min physics time interval



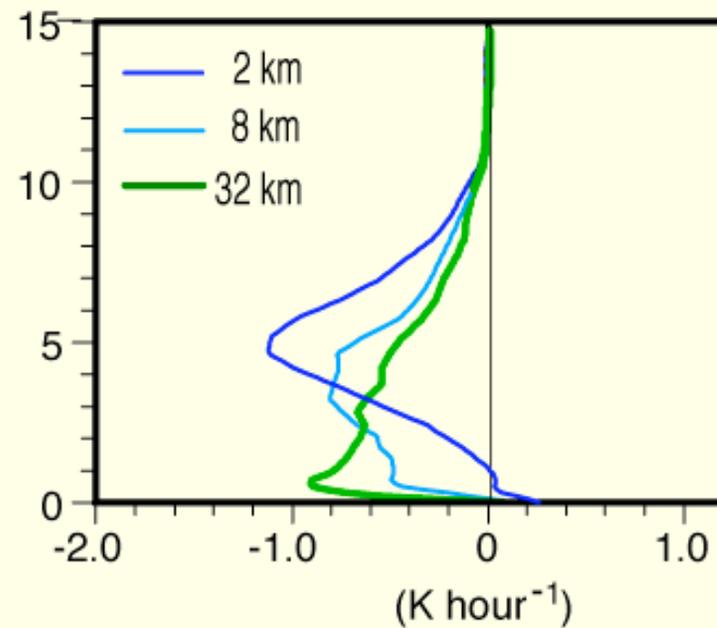
# Domain/Ensemble Average Profiles of "Required" Cloud-Microphysical Source

## Total Water Mixing Ratio

Physics time interval dependence  
with 2-km horizontal grid



Horizontal resolution dependence  
with 60 min physics time interval



# **A QUASI-3D SUPER-PARAMETERIZATION**

# A QUASI-3D SUPER-PARAMETERIZATION

## MOTIVATION

The conventional approach of cumulus parameterization is facing very difficult problems.

Improvement of weather prediction and climate models cannot wait until all of these problems are solved.

Computer technology is rapidly advancing.

Time is ripe to introduce multiple approaches, including an approach that requires the maximum use of available computer power.

# A QUASI-3D SUPER-PARAMETERIZATION

## STRATEGY

### Target (compromised)

A global 3D CRM

### Requirements

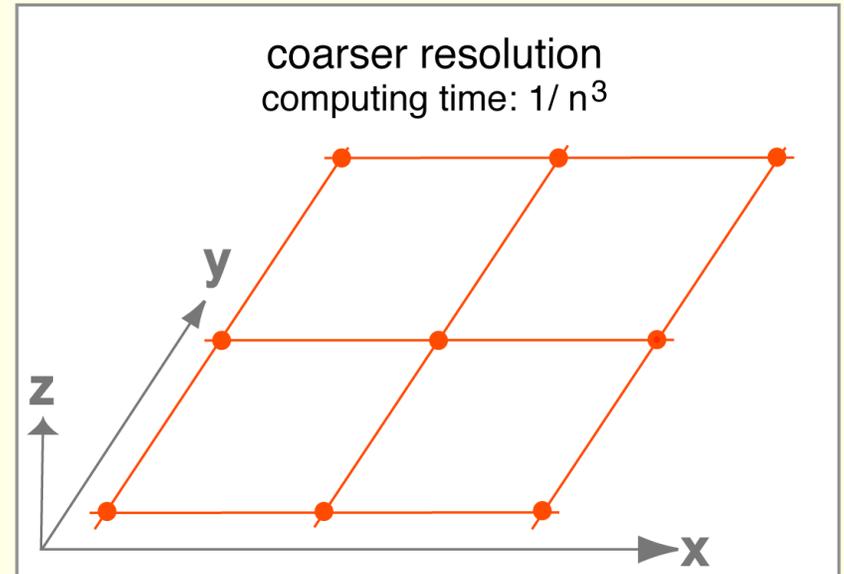
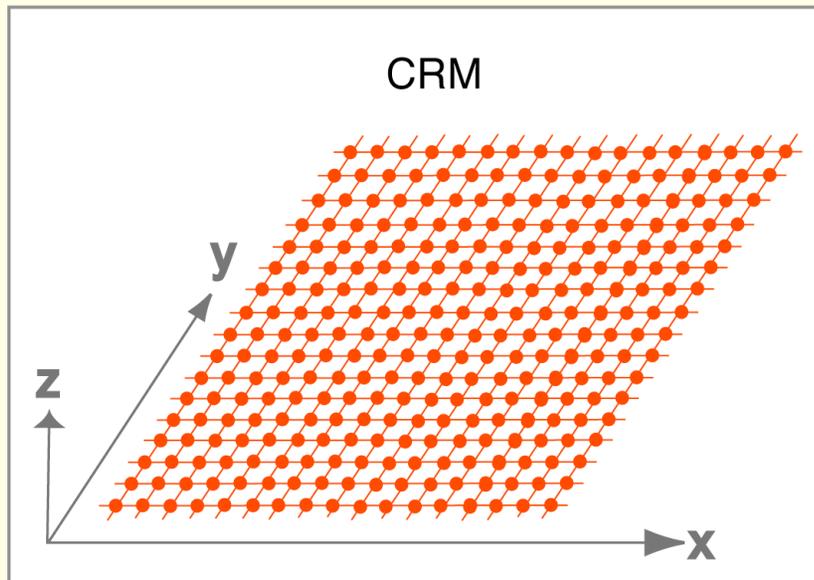
- An option for a global 3D CRM
- *Flexible*, less expensive options
- Same formulation of model physics for *all* options.

### Expected Outcome

- Guaranteed convergence to a global 3D CRM
- Better coordination of modeling efforts

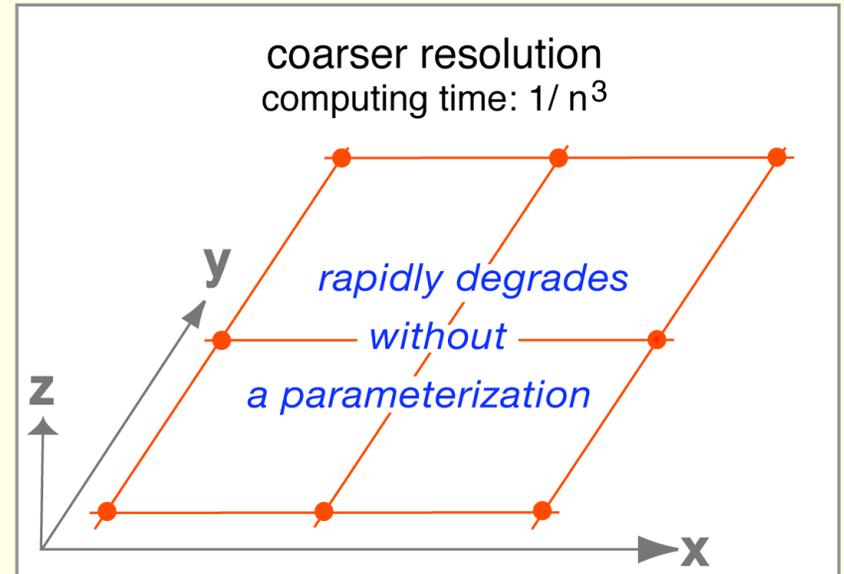
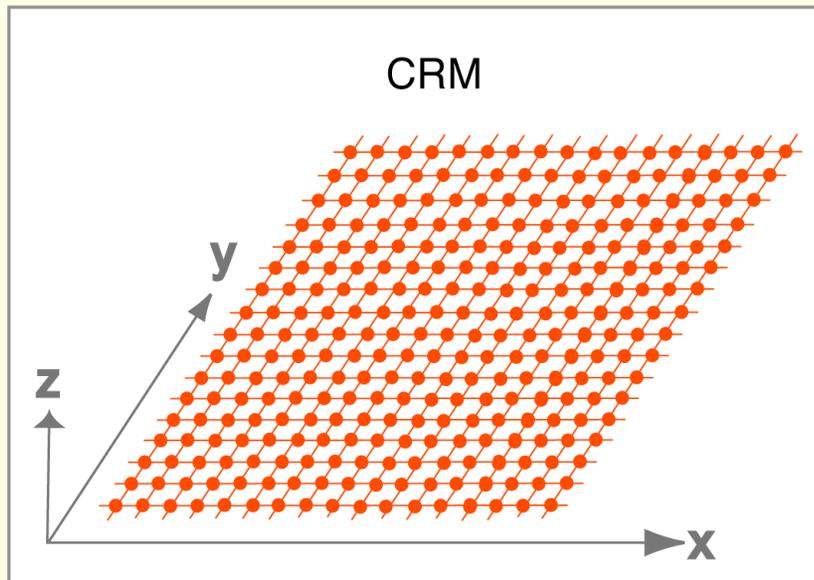
# GENERATION OF LESS-EXPENSIVE MODELS FROM A CRM

(Example: interval factor:  $n = 8$ )



# GENERATION OF LESS-EXPENSIVE MODELS FROM A CRM

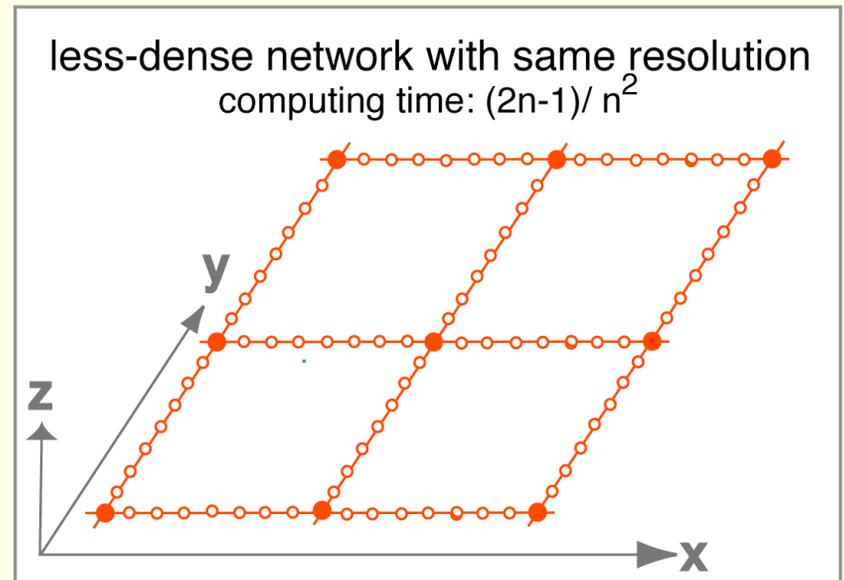
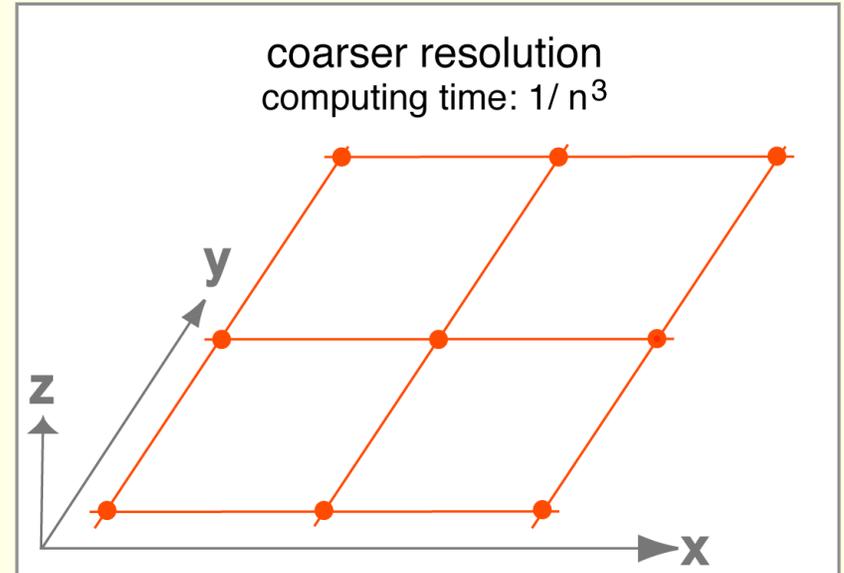
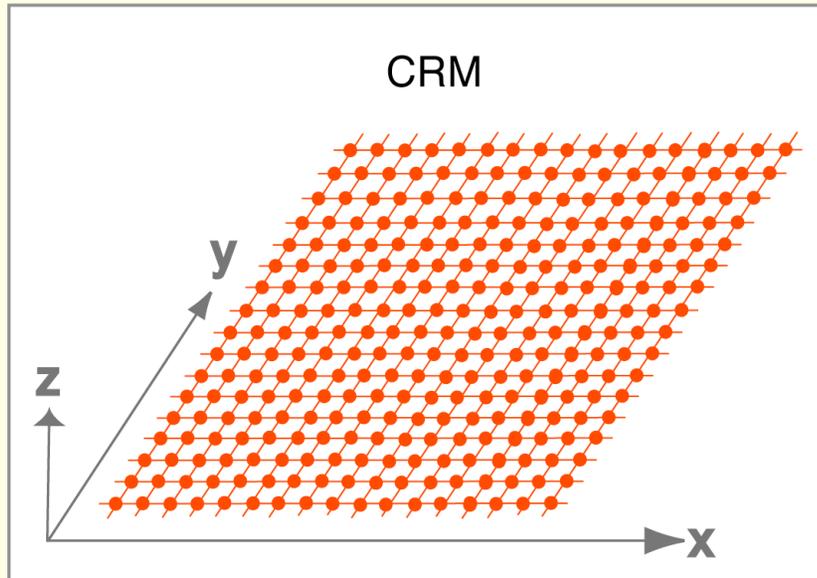
(Example: interval factor:  $n = 8$ )



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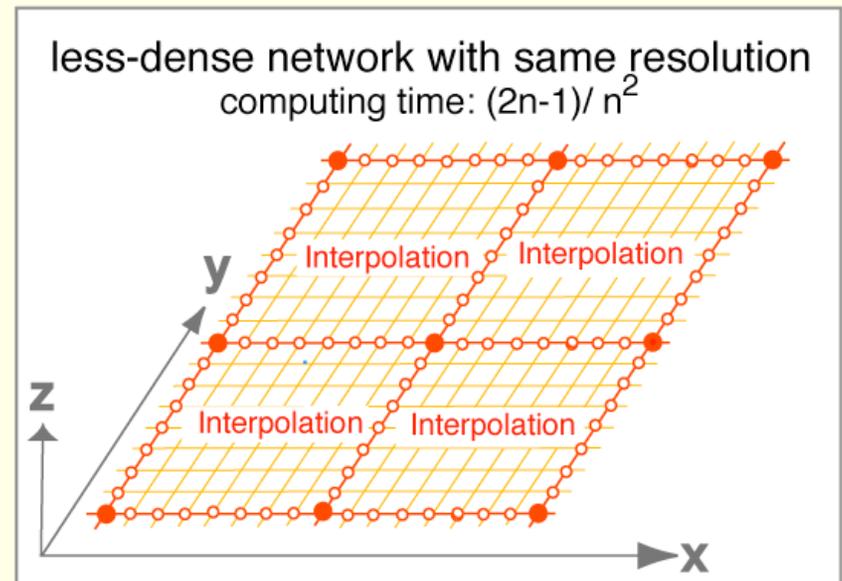
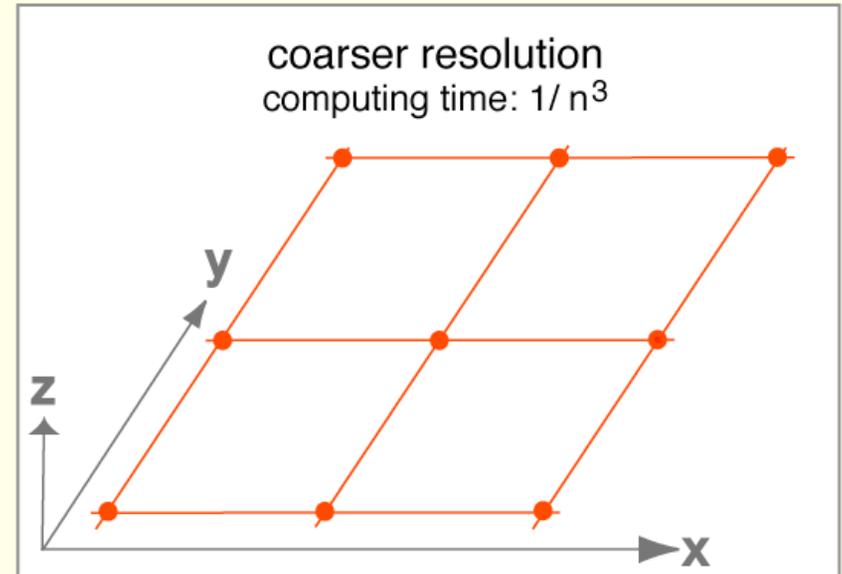
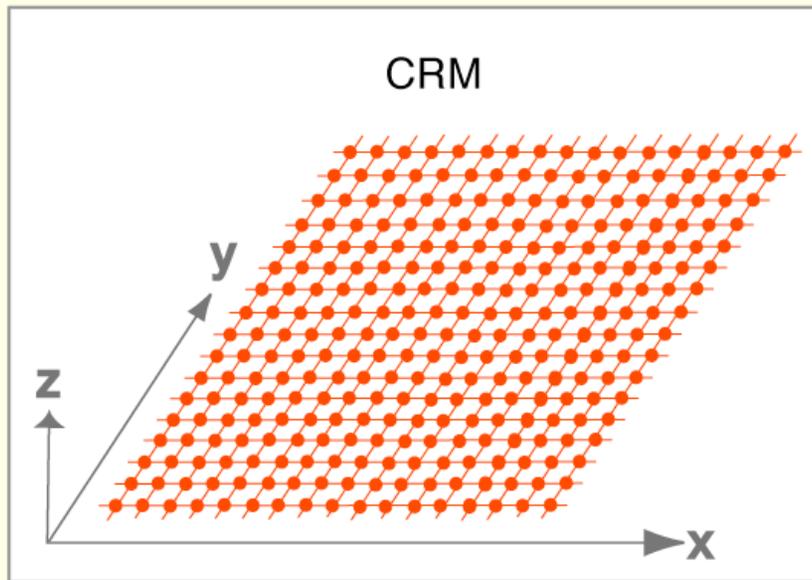
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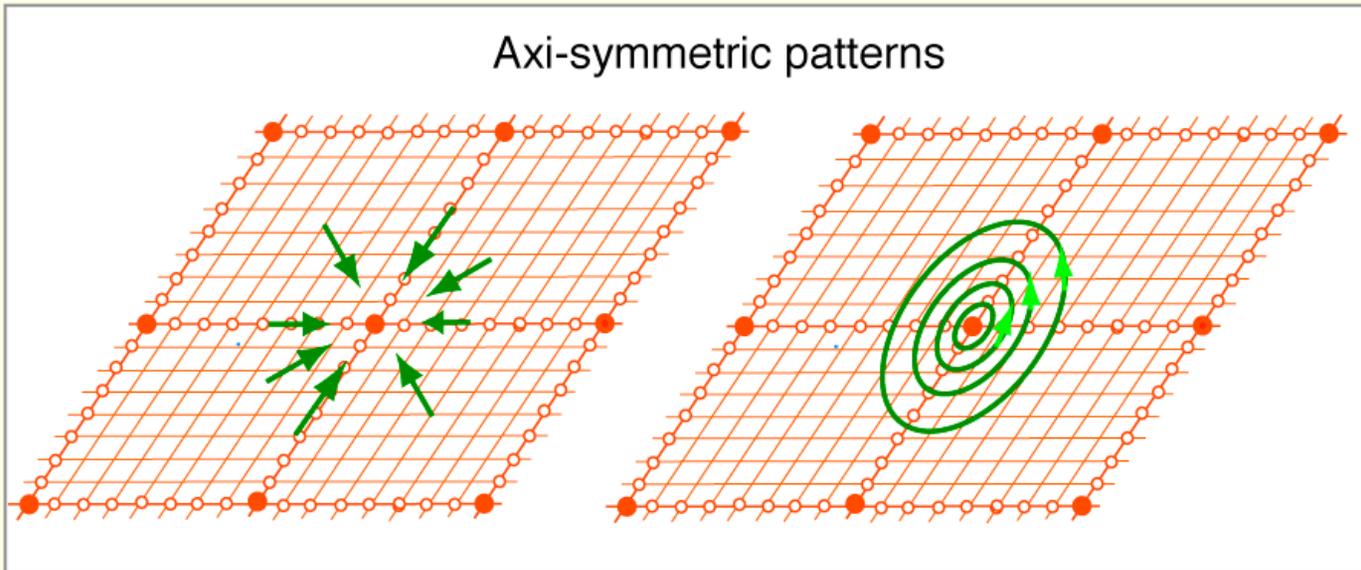


# GENERATION OF LESS-EXPENSIVE MODELS FROM A CRM

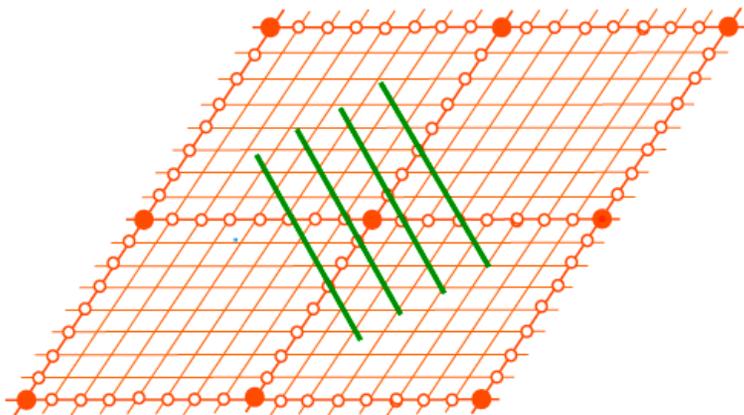
(Example: interval factor:  $n = 8$ )



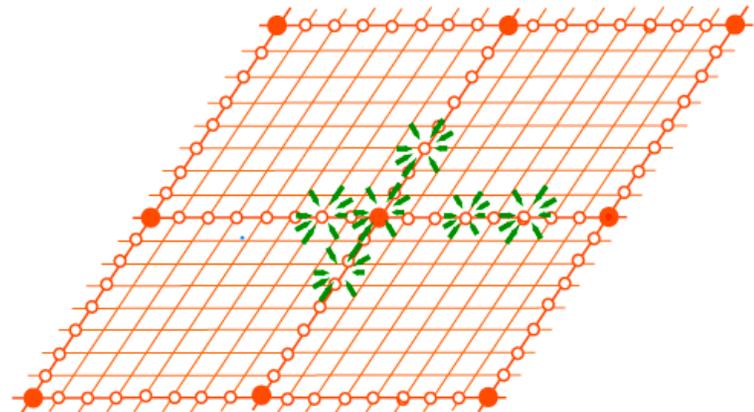
## EXAMPLES OF PATTERNS RECOGNIZABLE BY THE QUASI-3D CRM



Slab-symmetric patterns  
with arbitrary orientation



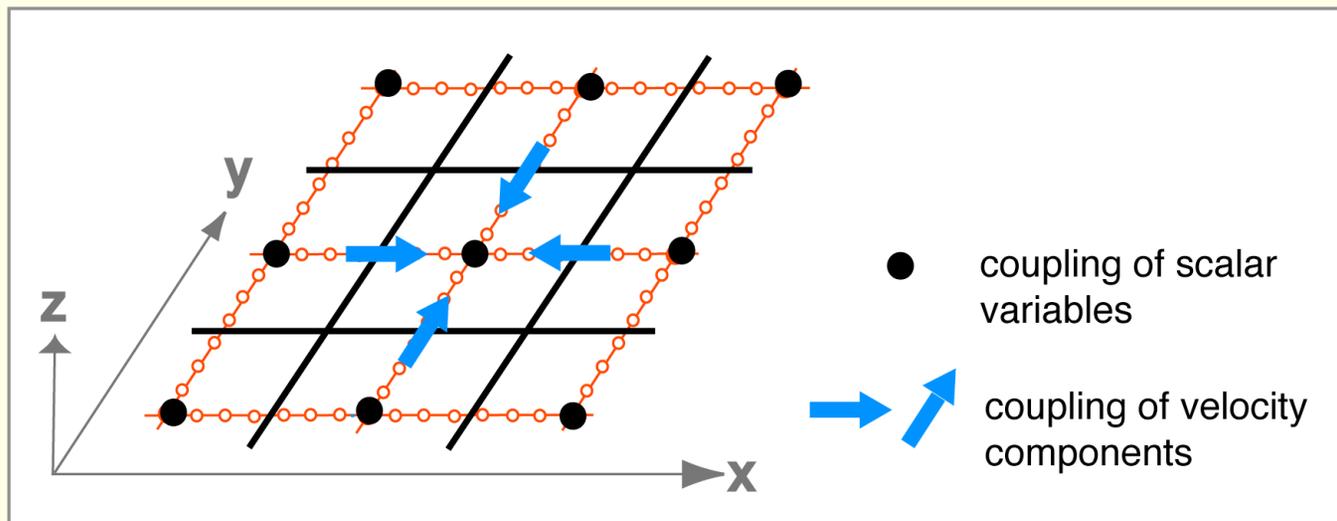
Statistics of small-scale features  
distributed along the axes



## QUASI-3D SUPER-PARAMETERIZATION:

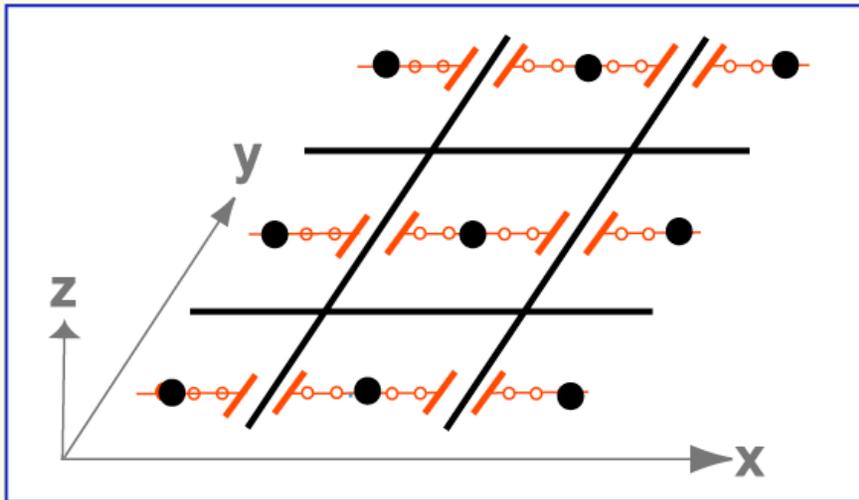
### COUPLED GCM / QUASI-3D CRM

- In principle, a quasi-3D CRM can replace GCMs entirely.
- It is better to use it as a "parameterization" in GCMs because
  - GCMs have more uniform grid point distributions for large-scales;
  - It is good to maintain compatibility with GCMs with conventional parameterizations.

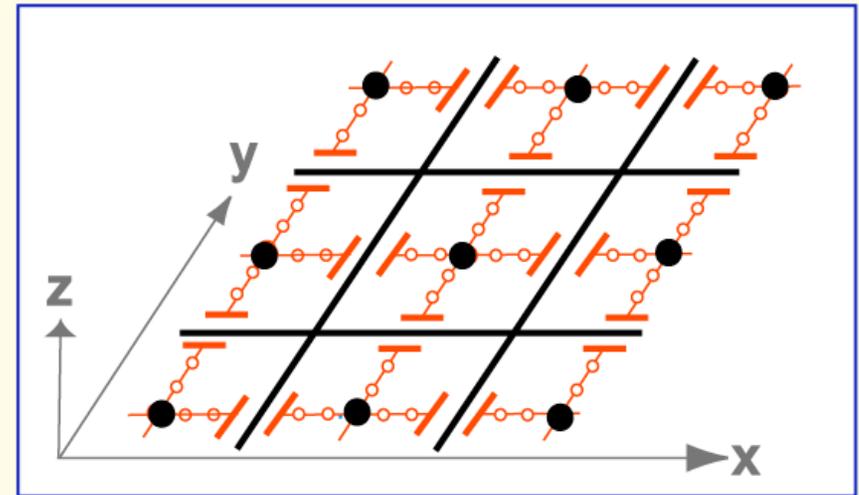


# RELATION WITH GRABOWSKI'S "CLOUD-RESOLVING CONVECTIVE PARAMETERIZATION"

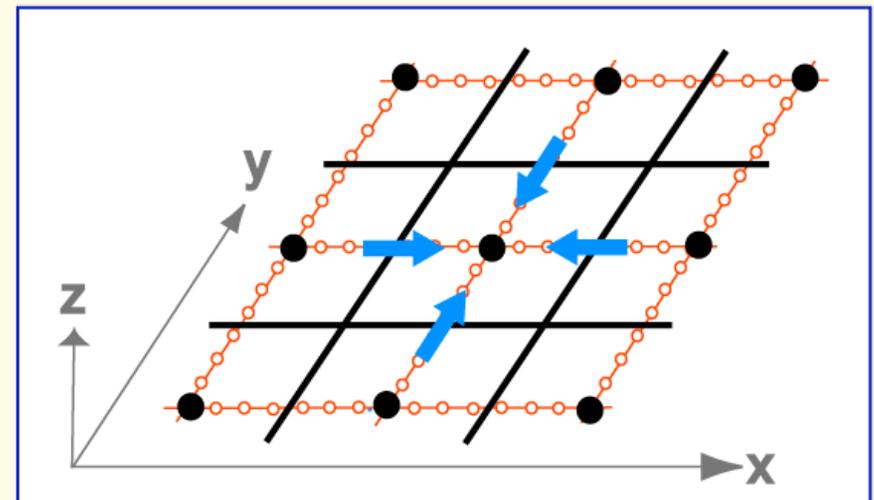
Original CRCP



Quasi-3D: confined



Quasi-3D: extended



## Advantages of eliminating cyclic boundary condition

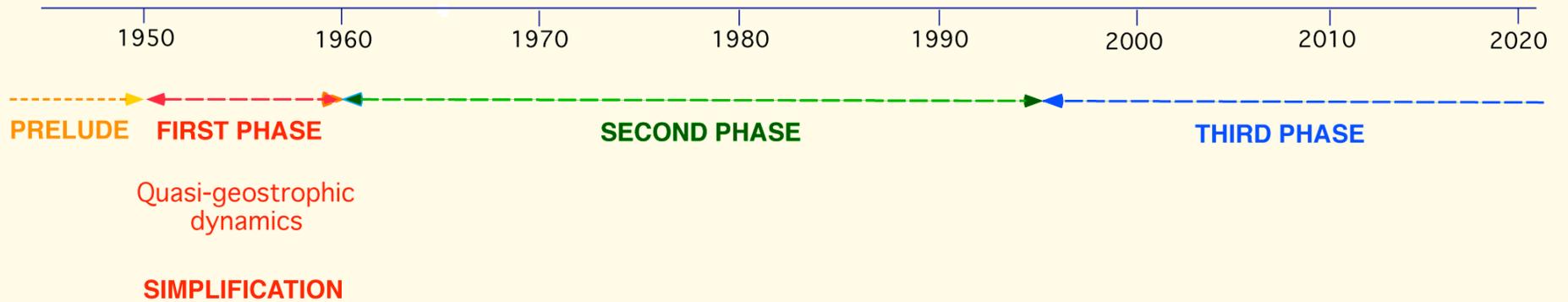
- Convective systems are not confined within a GCM grid box.
- The GCM and CRM share approximately the same mean vertical velocity and mean gradients of scalars.



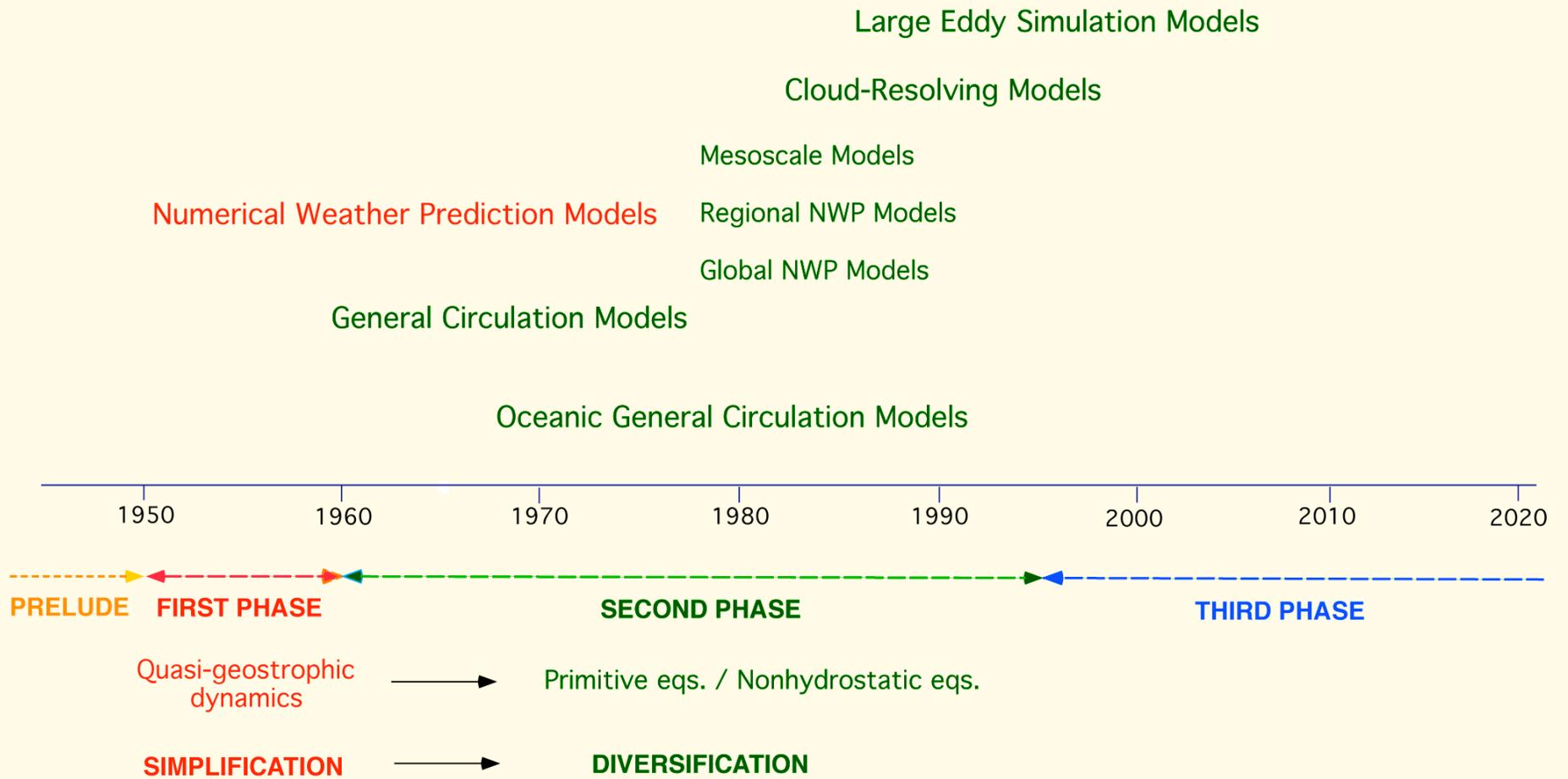
# HISTORY OF NUMERICAL MODELING OF THE ATMOSPHERE (AND OCEAN)

Numerical Weather Prediction Models

General Circulation Models



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