PROGRESS TOWARDS A QUASI-3D MMF

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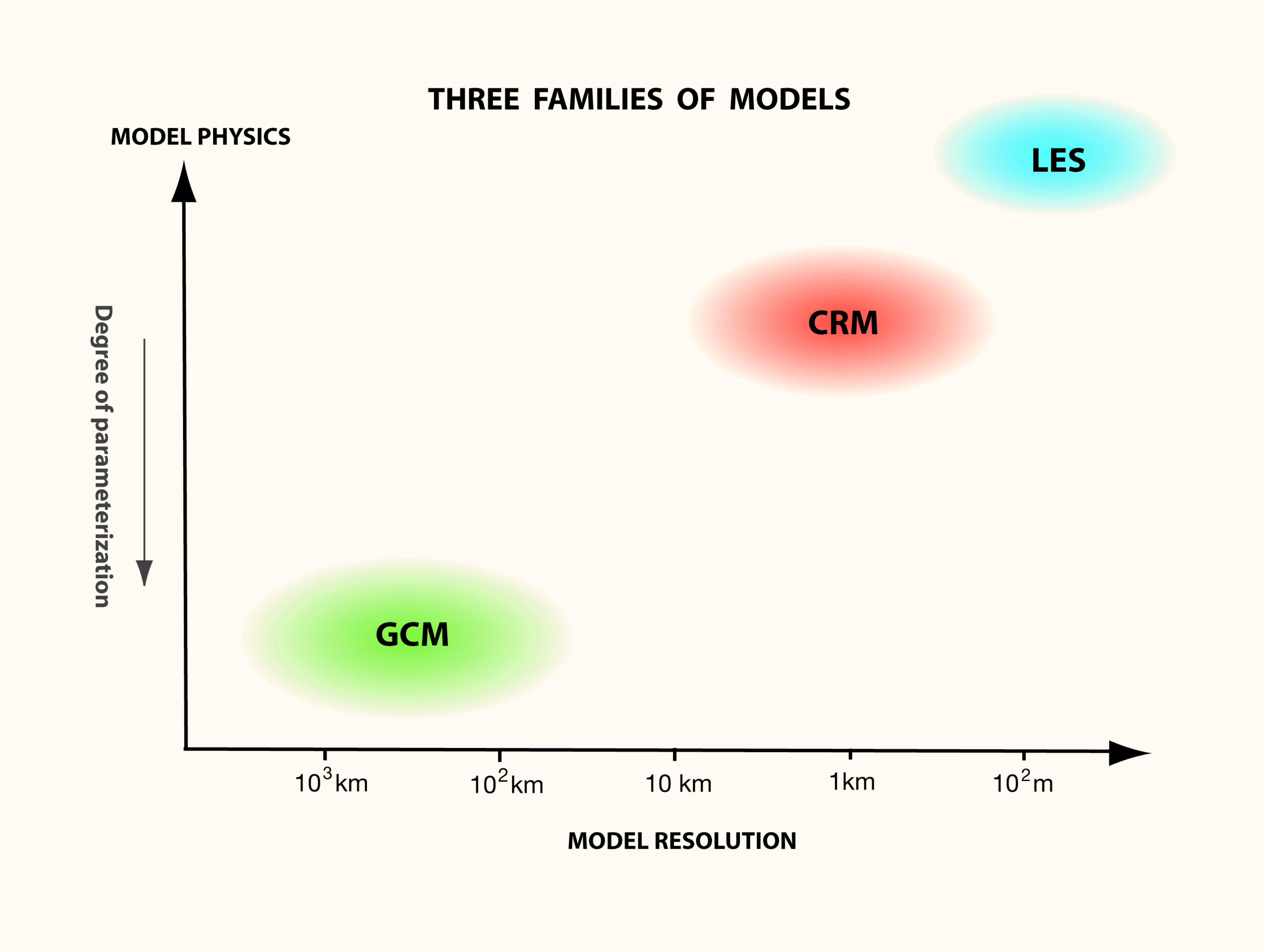
MOTIVATION AND GOAL

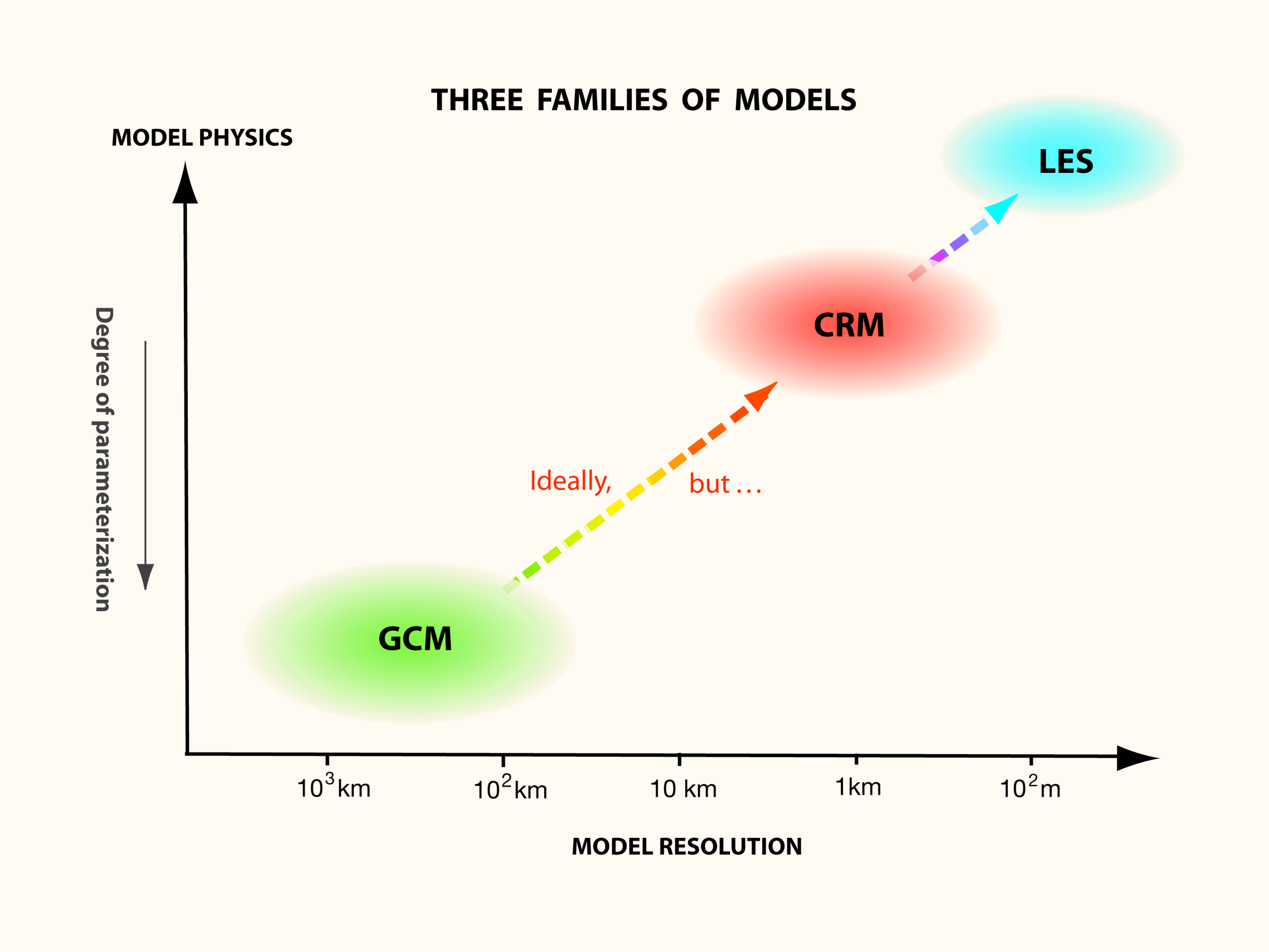
- Use of a discrete model can be justified when its solution converges to the solution of the original system as the resolution is refined.

- In numerical modeling of the atmosphere, model physics must also be changed as the resolution changes.

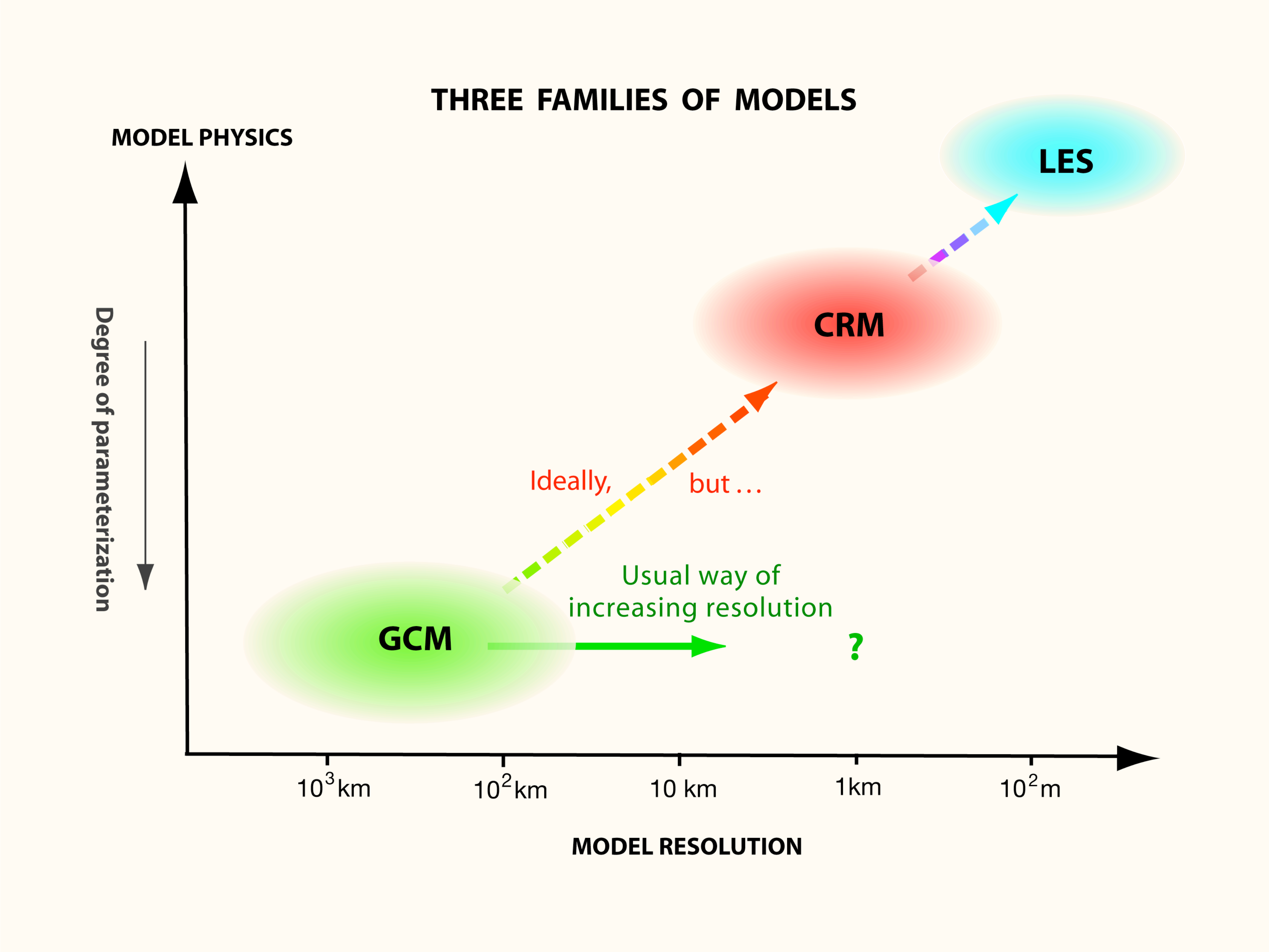
- Universal formulation of model physics applicable to a wide range of resolution doesn't exist.

The quasi-3D MMF is an attempt to fill this gap.

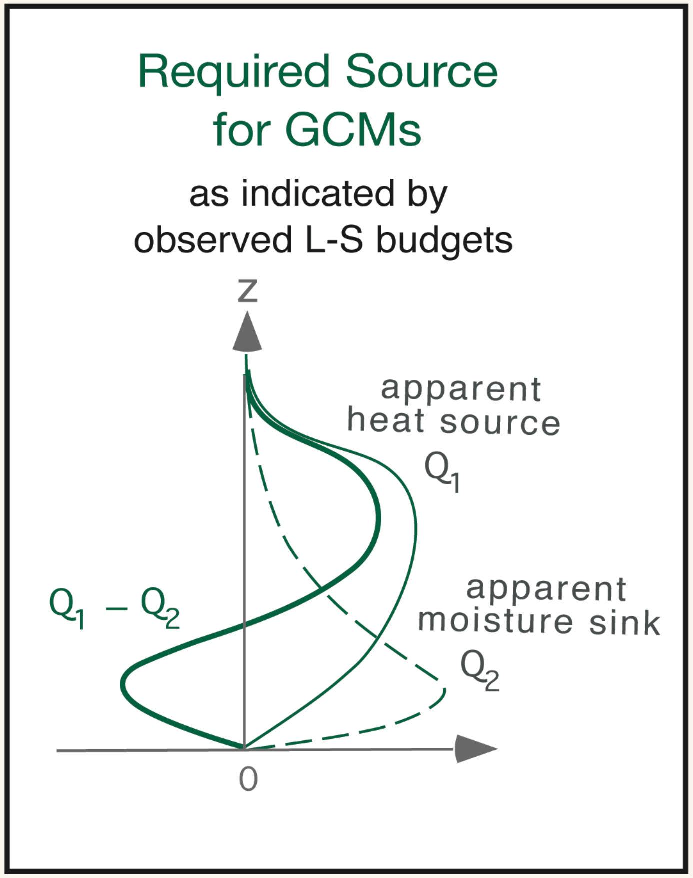

THREE FAMILIES OF MODELS
MODEL PHYSICS
Degree of parameterization
LES
CRM
GCM
10^3 km
10^2 km
10 km
1km
10^2 m
MODEL RESOLUTION

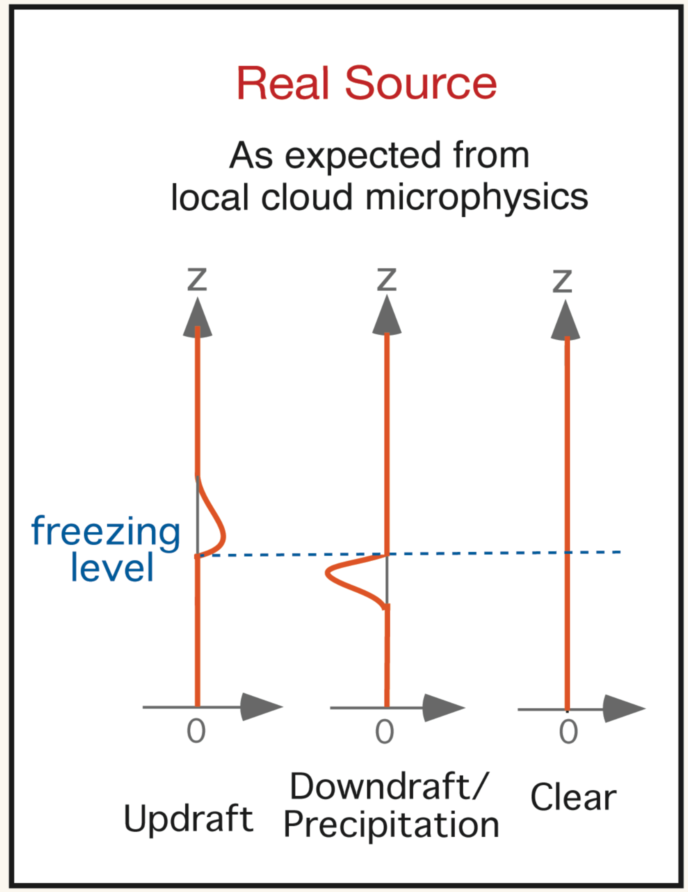


THREE FAMILIES OF MODELS
MODEL PHYSICS
Degree of parameterization
LES
CRM
GCM
Ideally,
but . . .
10^3 km
10^2 km
10 km
1km
10^2 m
MODEL RESOLUTION

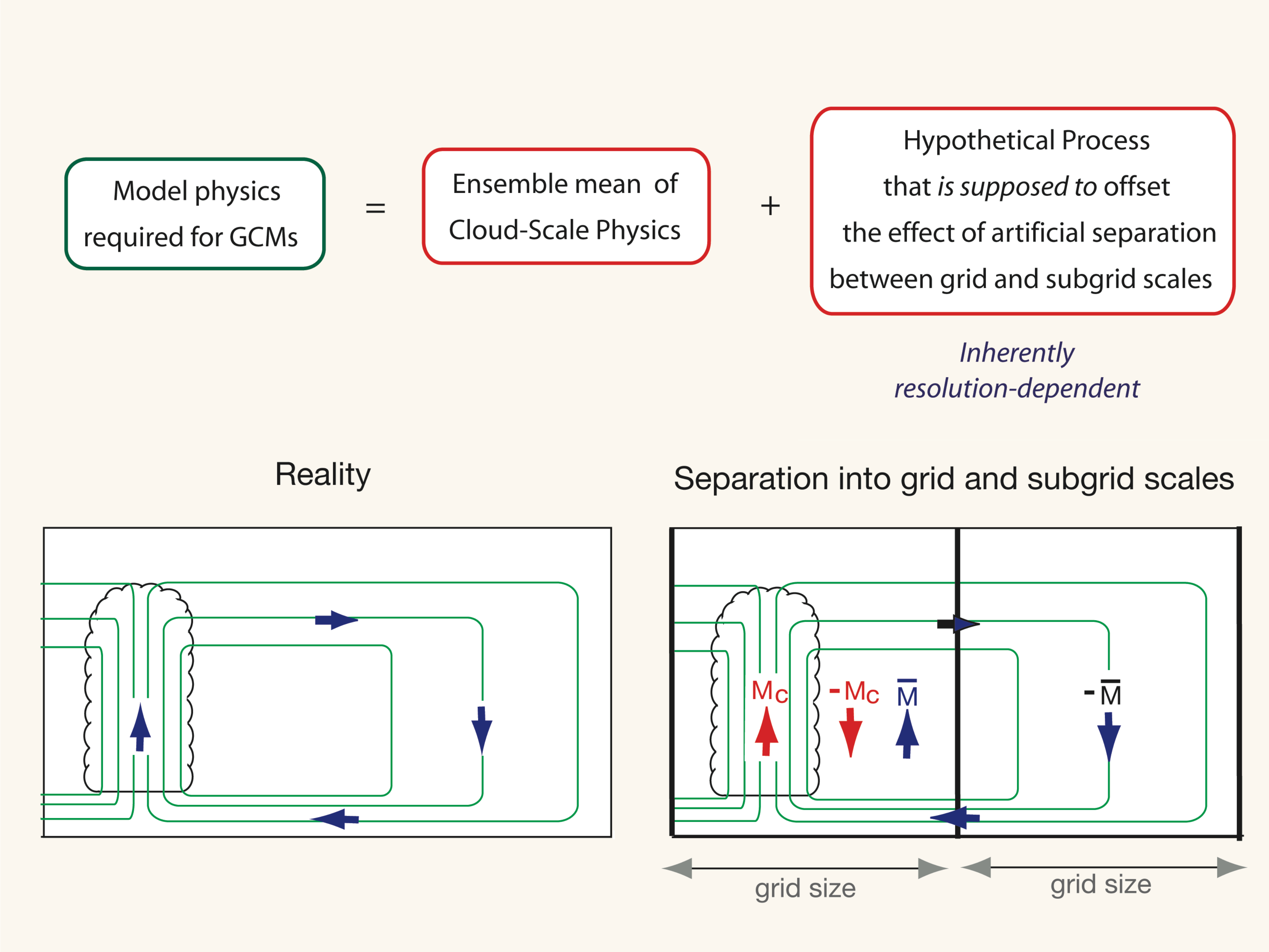

THREE FAMILIES OF MODELS
MODEL PHYSICS
Degree of parameterization
LES
CRM
Ideally,
but …
Usual way of
increasing resolution
GCM
?
10^3 km
10^2 km
10 km
1km
10^2 m
MODEL RESOLUTION

TYPICAL VERTICAL PROFILES OF MOIST STATIC ENERGY SOURCE DUE TO DEEP CONVECTION

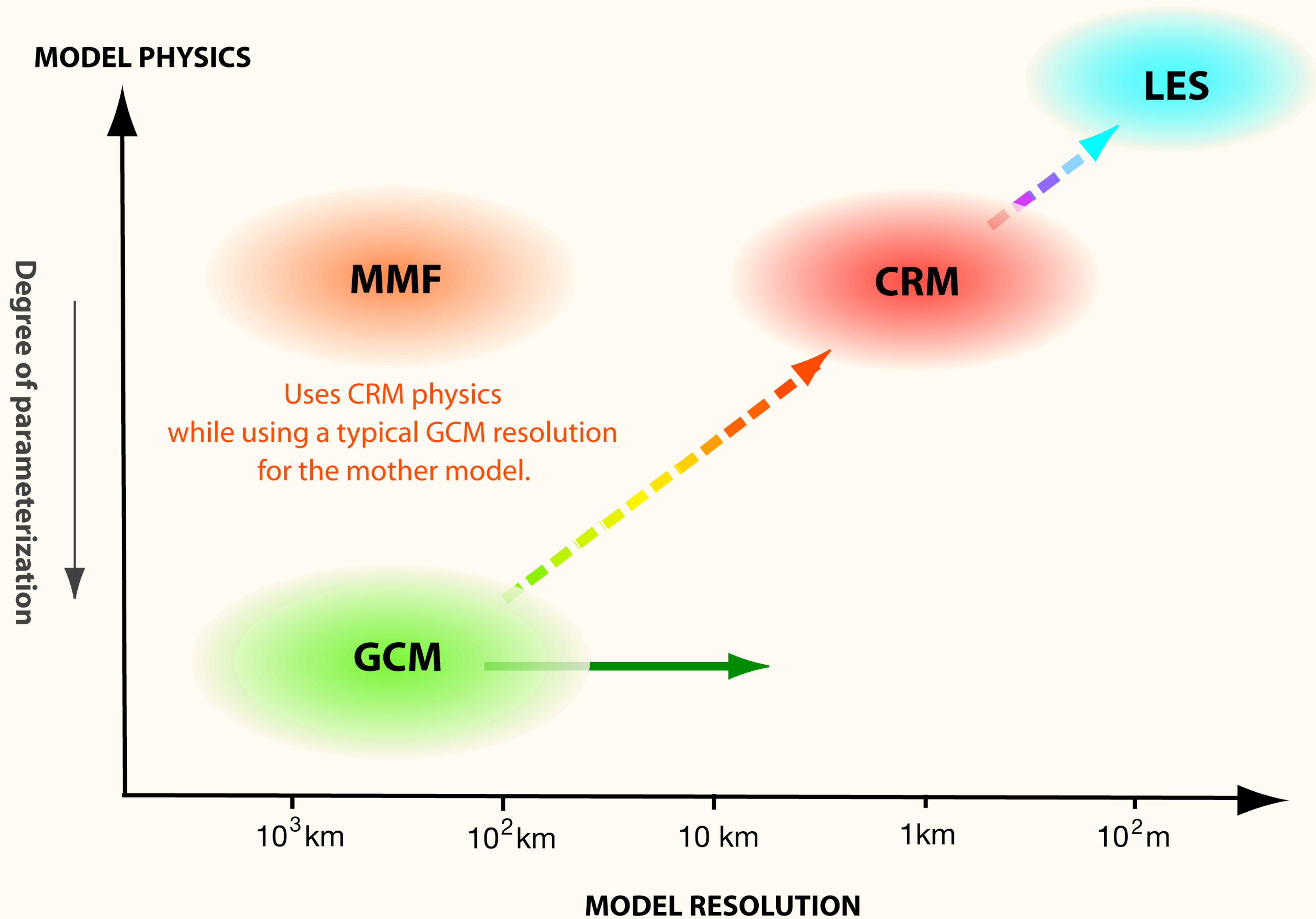


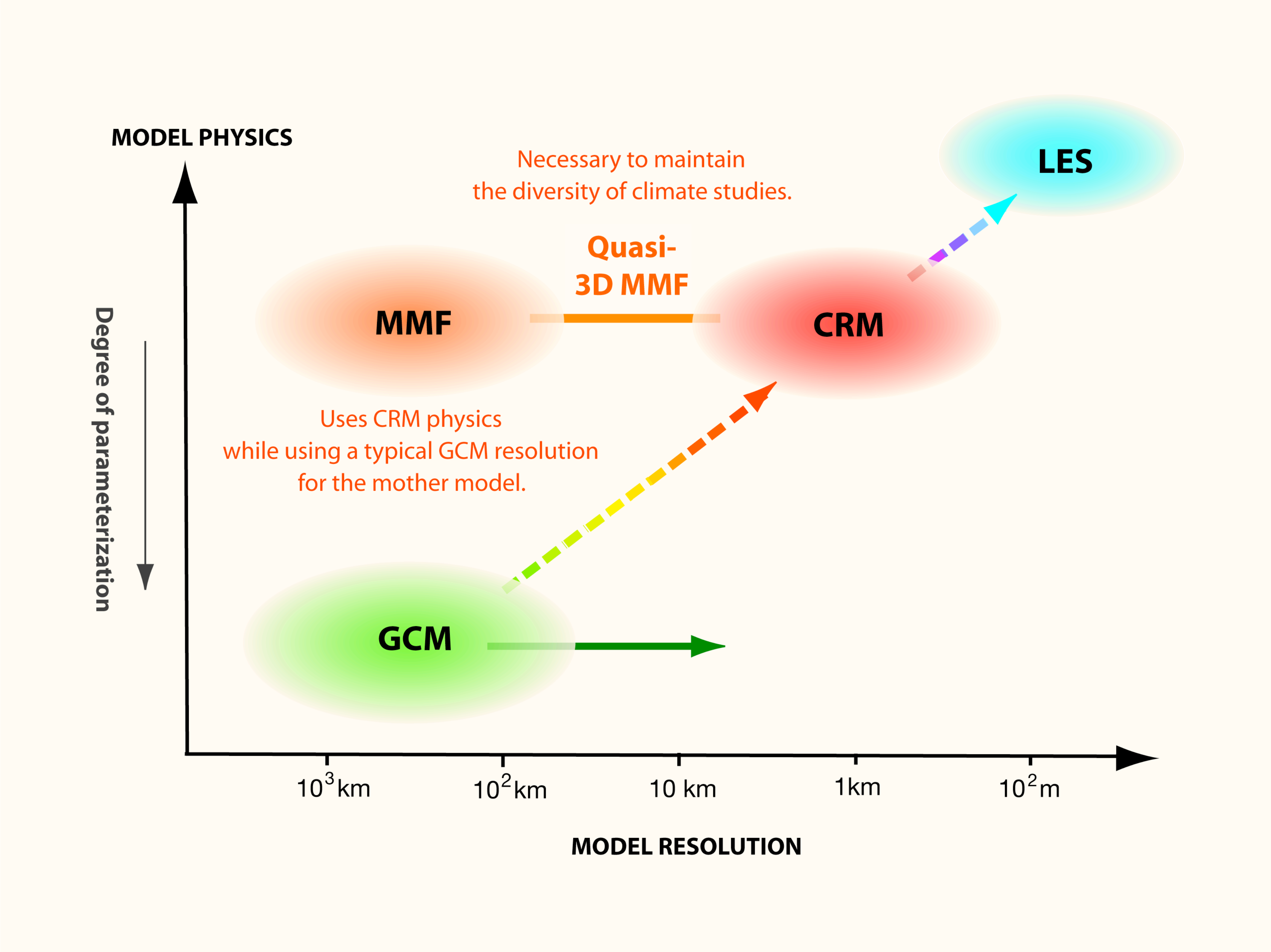


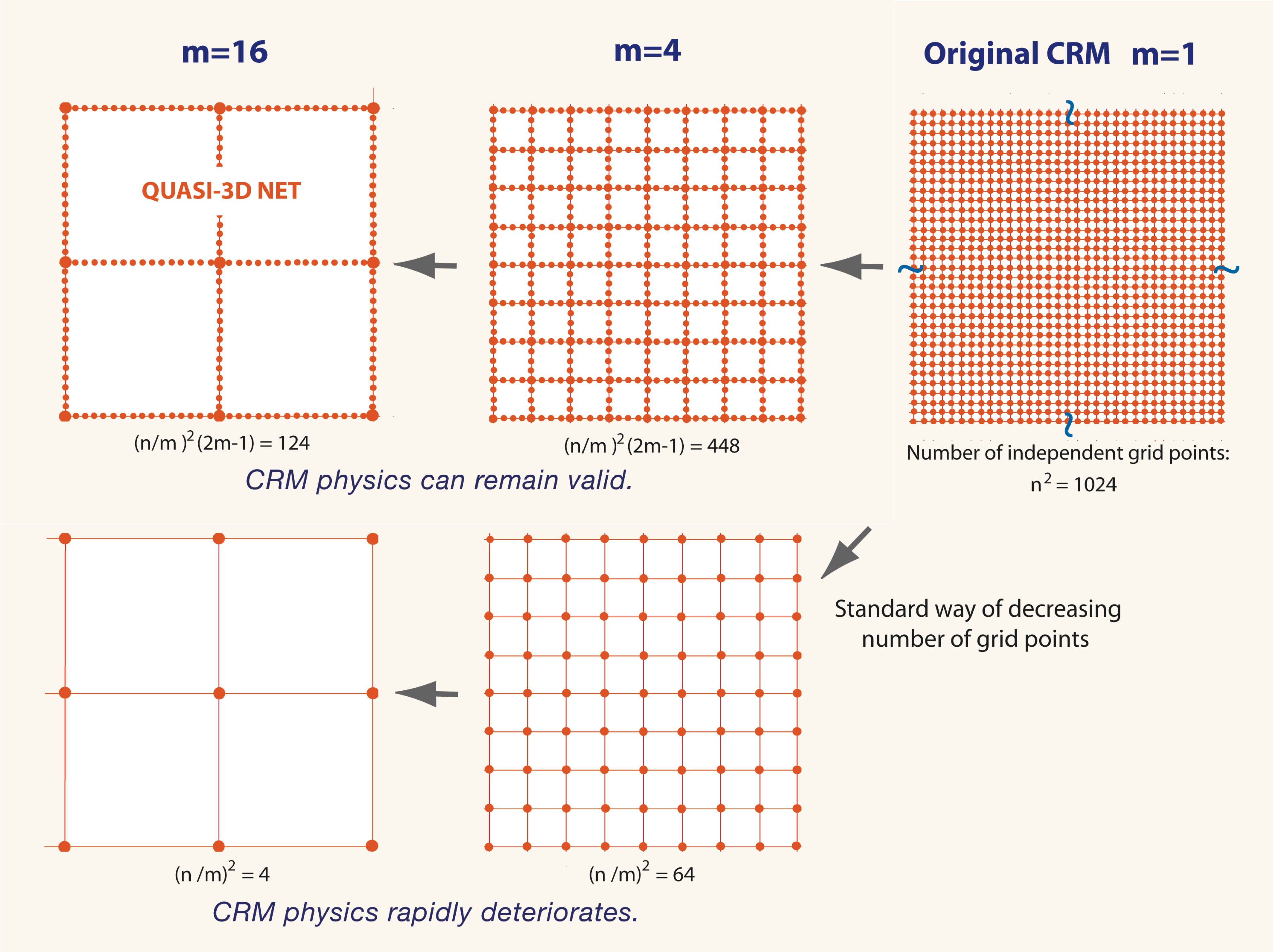
Any space/time/ensemble average of the profiles in the right panel does NOT give the profile in the left panel.



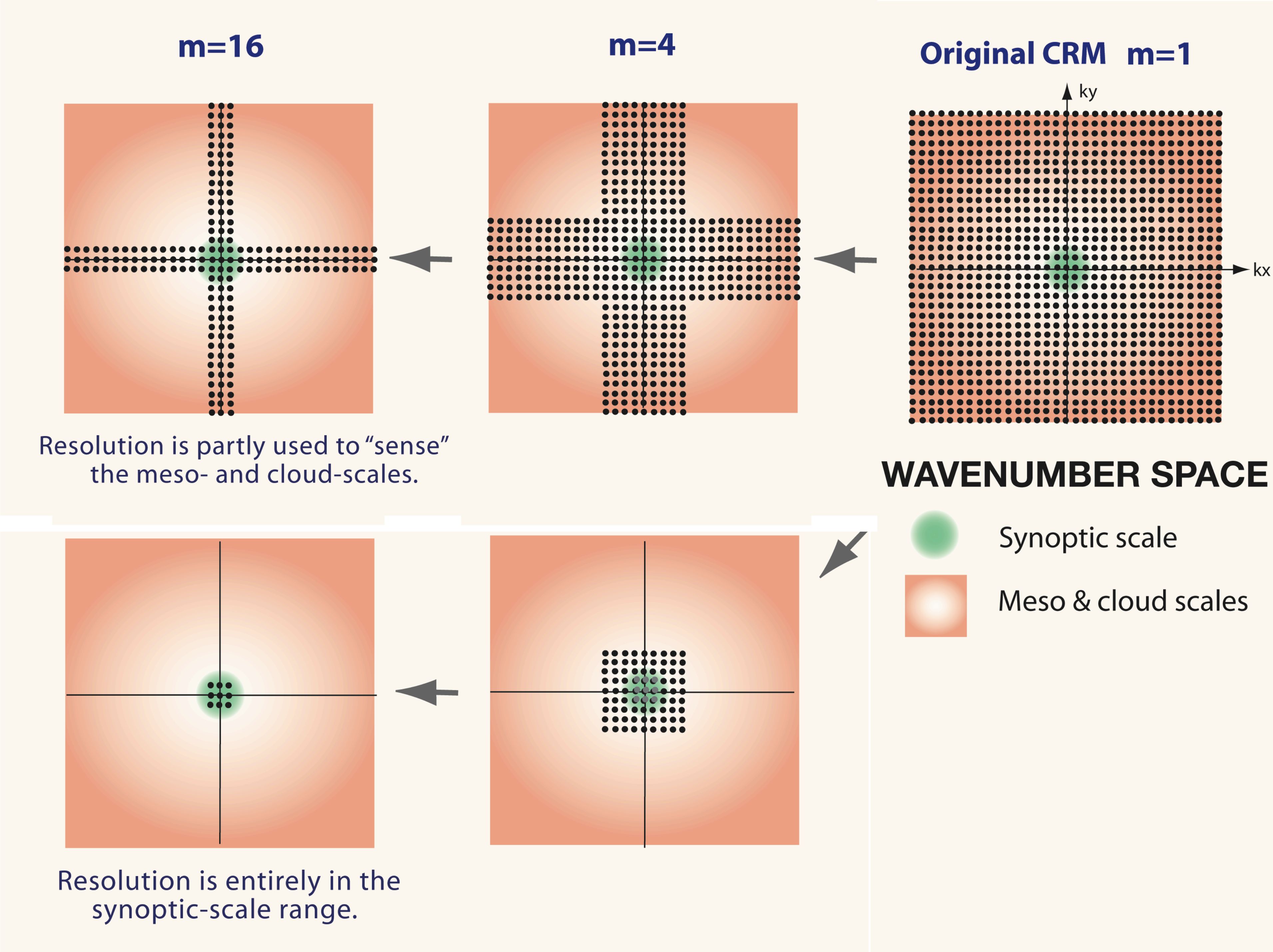
Model physics required for GCMs
=
Ensemble mean of Cloud-Scale Physics
+
Hypothetical Process that *is supposed to* offset the effect of artificial separation between grid and subgrid scales
Inherently resolution-dependent
Reality
Separation into grid and subgrid scales
Mc
-Mc
M̄
-M̄
grid size
grid size

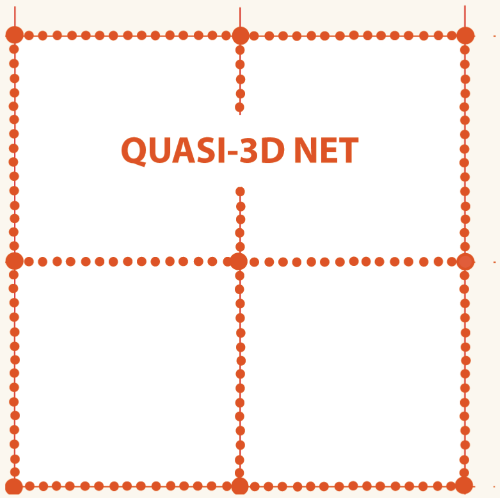

MODEL PHYSICS
LES
MMF
CRM
Degree of parameterization
Uses CRM physics
while using a typical GCM resolution
for the mother model.
GCM
10^3 km
10^2 km
10 km
1km
10^2 m
MODEL RESOLUTION


MODEL PHYSICS
Necessary to maintain
the diversity of climate studies.
LES
Quasi-
3D MMF
MMF
CRM
Degree of parameterization
Uses CRM physics
while using a typical GCM resolution
for the mother model.
GCM
10³km
10²km
10 km
1km
10²m
MODEL RESOLUTION

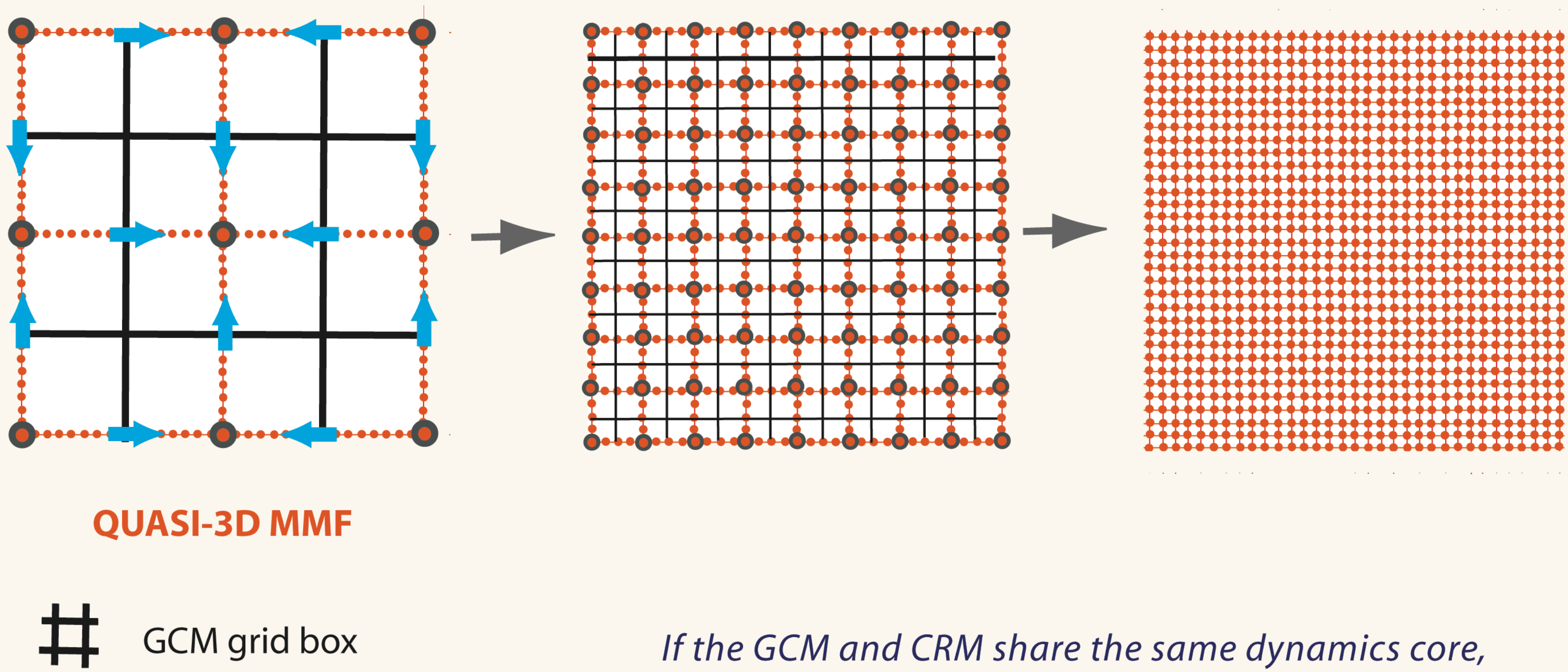


m=16
m=4
Original CRM m=1
QUASI-3D NET
(n/m)^2 (2m-1) = 124
(n/m)^2 (2m-1) = 448
Number of independent grid points:
n^2 = 1024
CRM physics can remain valid.
Standard way of decreasing number of grid points
(n /m)^2 = 4
(n /m)^2 = 64
CRM physics rapidly deteriorates.


m=16
m=4
Original CRM m=1
ky
kx
Resolution is partly used to "sense" the meso- and cloud-scales.
WAVENUMBER SPACE
Synoptic scale
Meso & cloud scales
Resolution is entirely in the synoptic-scale range.



This highly anisotropic grid is not appropriate for large-scale dynamics.



If the GCM and CRM share the same dynamics core,

the quasi-3D MMF converges to the 3D CRM

as the GCM grid is refined.

Decomposition of Fields

$$q = \overline{q} + q',$$

where

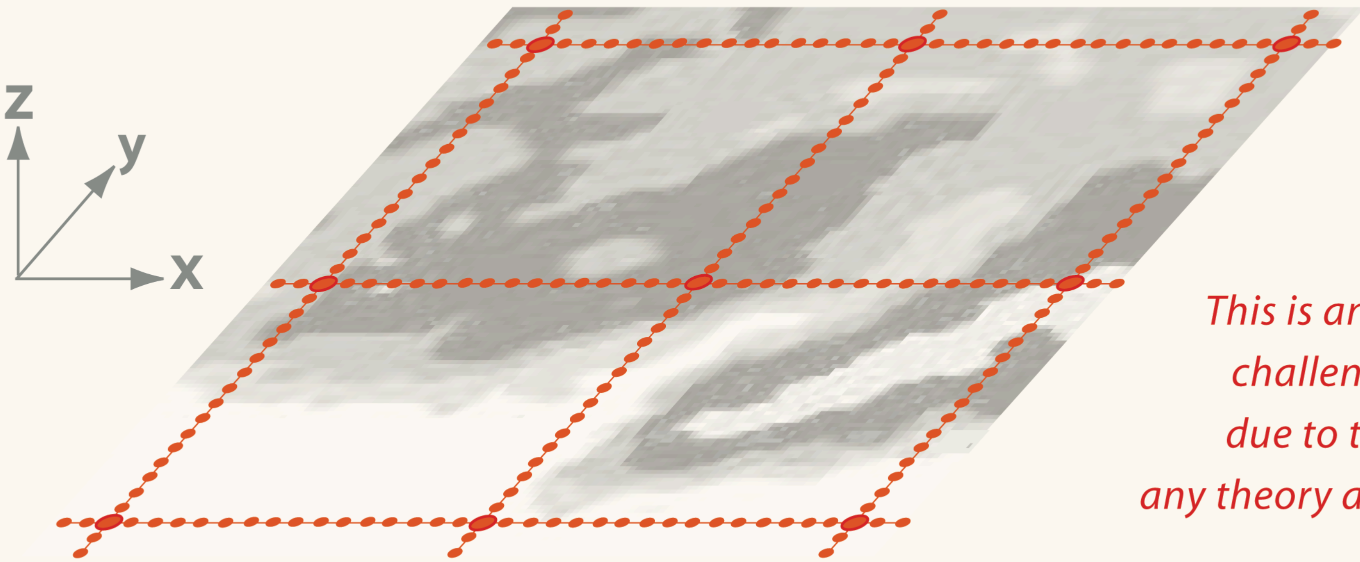
$\overline{q}$: Background field obtained by interpolation of GCM grid-point values, typically representing synoptic-scale fields

q' : Deviation of q from $\overline{q}$, typically representing the fields associated with clouds and their mesoscale organizations

The quasi-3D CRM concentrates on prediction of the q' field.

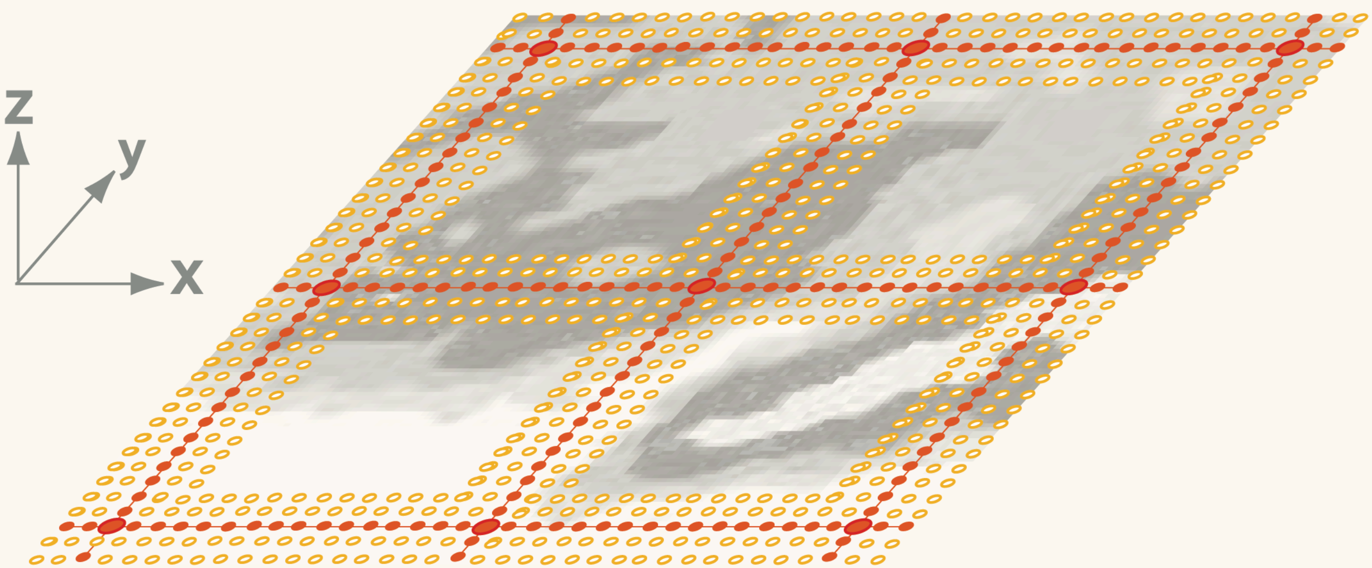
We apply formally the same 3D algorithm to all grid points .

- Then, except at the intersection points, we have to “estimate” advection in the direction normal to the grid-point arrays.
- Also, to solve the elliptic equation, we have to “estimate“ the second-order derivatives in the direction normal to the grid-point arrays.



This is an extremely challenging task due to the lack of any theory and experience.

We first introduce “ghost points” along the grid-point arrays.



Design of a Quasi-3D Advection Algorithm

Guided by considerations of the following requirements when it is used in a prognostic mode:

I. Stability (global and local);

II. Recognition of dominant orientation of cloud organization;

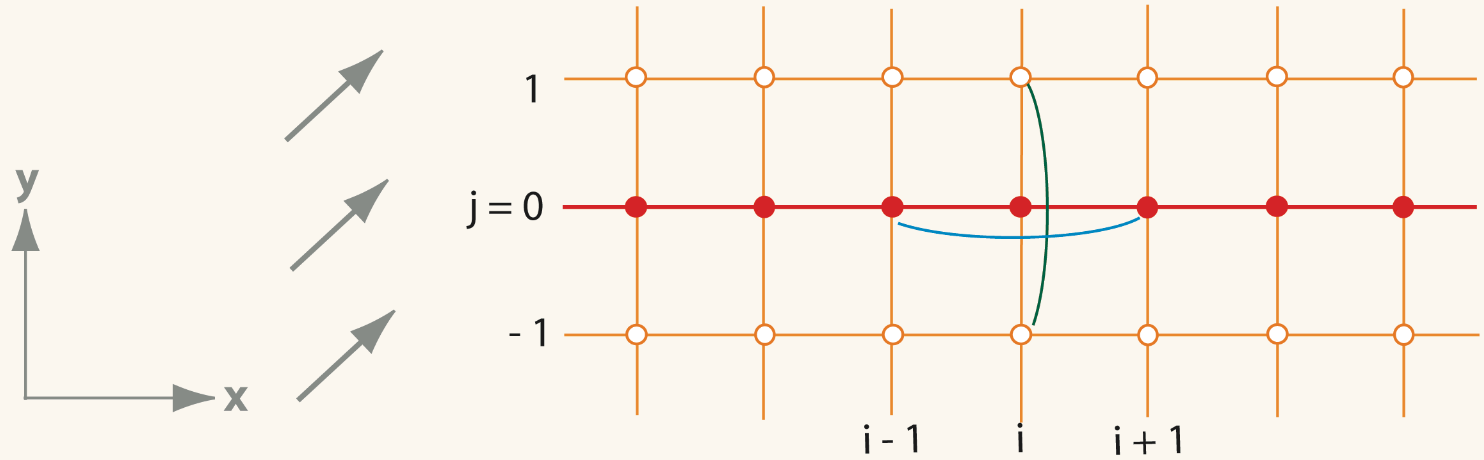
III. Possibility of incorporating stochastic components;

IV. Conservation of the vertically-integrated network mean;

V. Control of spurious trend.

(The following description assumes that the model uses second-order finite differences.)

Global Stability : Uniform current with $\overline{q'}^{i} = 0$



The array sum of q'^2 is conserved if $\Delta_j \hat{q}'$ is not correlated with q'.

$$\Delta_j \hat{q}' = a_1 + b_1 \Delta_i q' + f_1$$

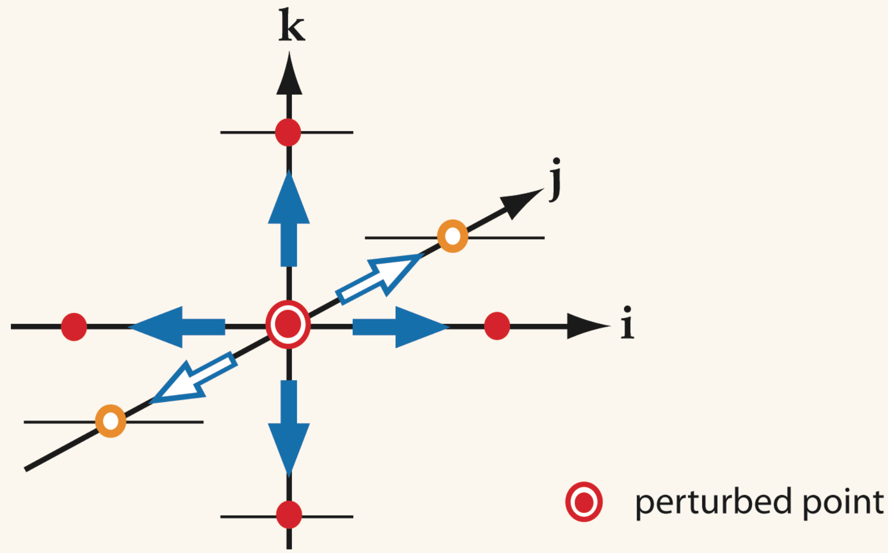
$\Delta_j \hat{q}'$: Estimated first-order difference in the normal direction

$\Delta_i q'$: Predicted first-order difference in the tangential direction

f_1: A stochastic function

The parameter b_1 represents the dominant orientation of cloud organization.

Local Stability : Three-dimensionally variable current



Estimated flux divergence must not produce a positive feedback on the perturbation.

$$\delta_j^2 \widehat{q'} = a_2 + b_2 \, \delta_i^2 q' + f_2$$

- $\delta_j^2 \widehat{q'}$: Estimated second-order difference in the normal direction
- $\delta_i^2 q'$: Predicted first-order difference in the tangential direction
- f_2: A stochastic function

with $b_2 \geq 1$

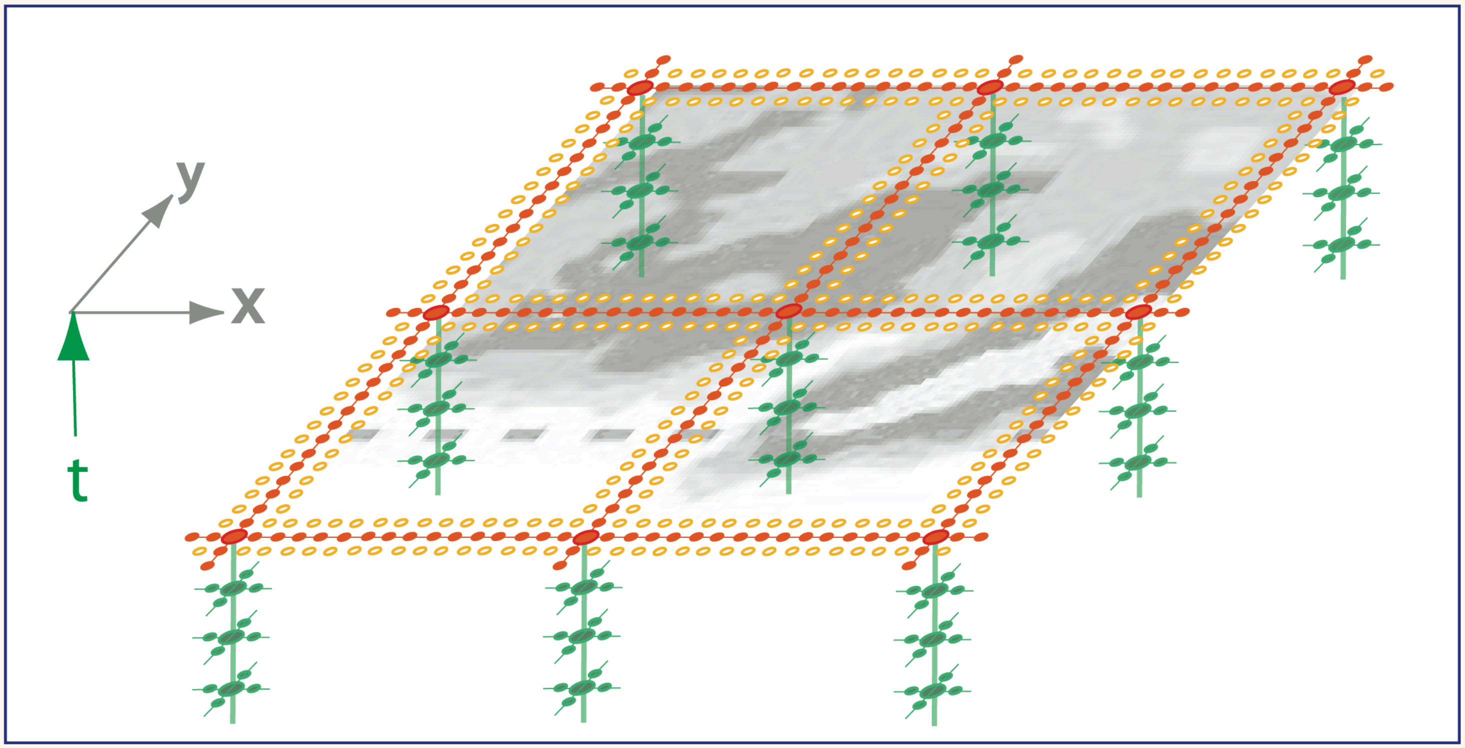
$$\Delta_j \widehat{q'} = a_1 + b_1 \, \Delta_i \widehat{q'} + f_1$$

$$\delta_j^2 \widehat{q'} = a_2 + b_2 \, \delta_i^2 \widehat{q'} + f_2$$

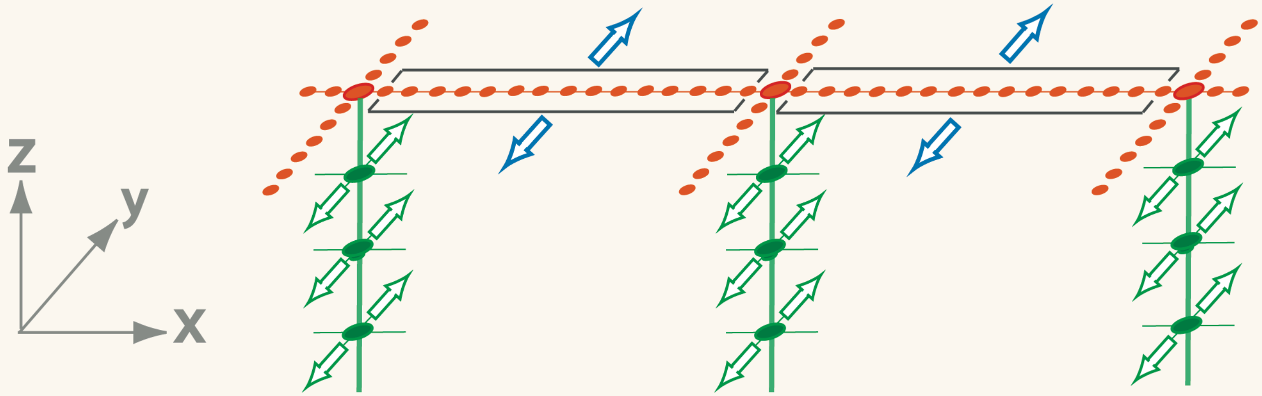
These parameters and functions are cloud-regime dependent.

Hypotheses

- *Cloud regimes have longer spatial and temporal scales than individual clouds.*
- *These parameters and functions can be statistically estimated from the history of the intersection and neighboring points.*



Conservation



(Approximate) conservation is achieved by requiring

the mean divergence of the flux from/to ghost points are equal to the divergence of the flux in the same direction at intersection points averaged over a selected period in the past.

Solving elliptic equation using the quasi-3D network

The model we are using is based on the 3D vorticity equation
with an anelastic approximation and solves an elliptic equation for w.

- The elliptic equation is converted to a parabolic equation whose equilibrium solution is the solution of the elliptic equation (mimicing the relaxation method).

- The secnd-order finite difference in the normal direction is estimated as in the advection problem.

TESTING PERFORMED SO FAR

for an idealized, very small domain first

Diagnostic Tests

↓

Partially Prognostic Tests (with no stochastic components)

Advection with prescribed winds (and potential temperature).

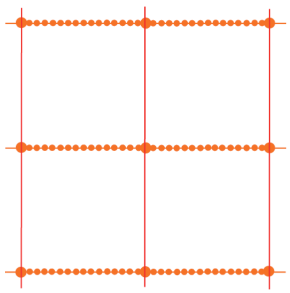
- Tracer
- Different phases of water with physics

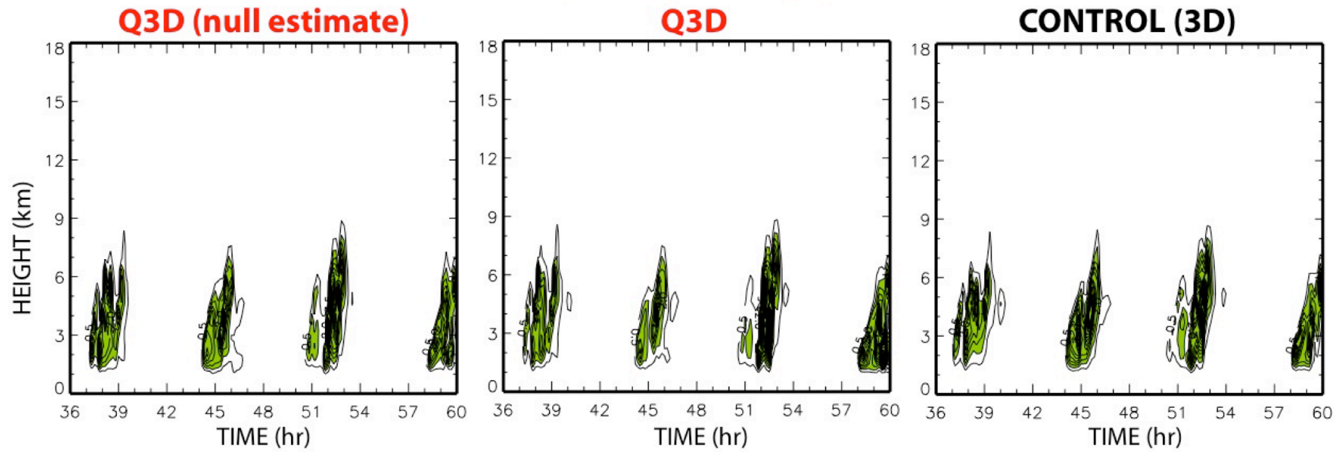
Calculation of wind components from pescribed vorticity fields

The results of these tests are encouraging and we are almost ready to proceed to fully pognostivc tests.

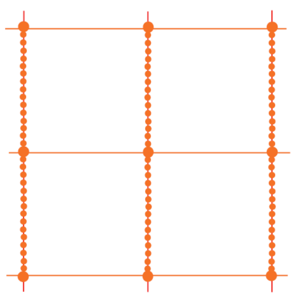
$q_c'^2$

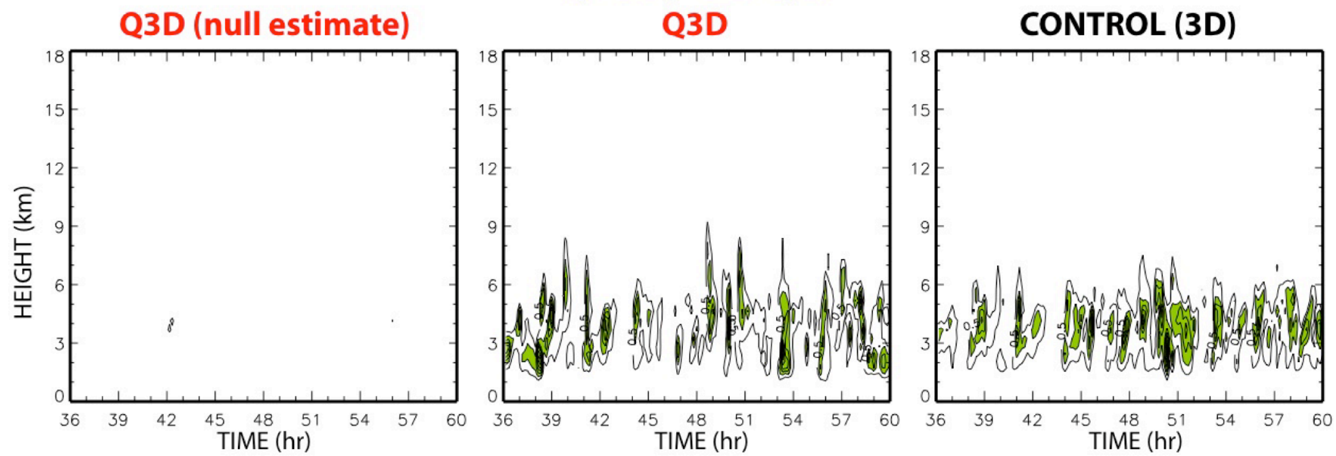
(x-array average)



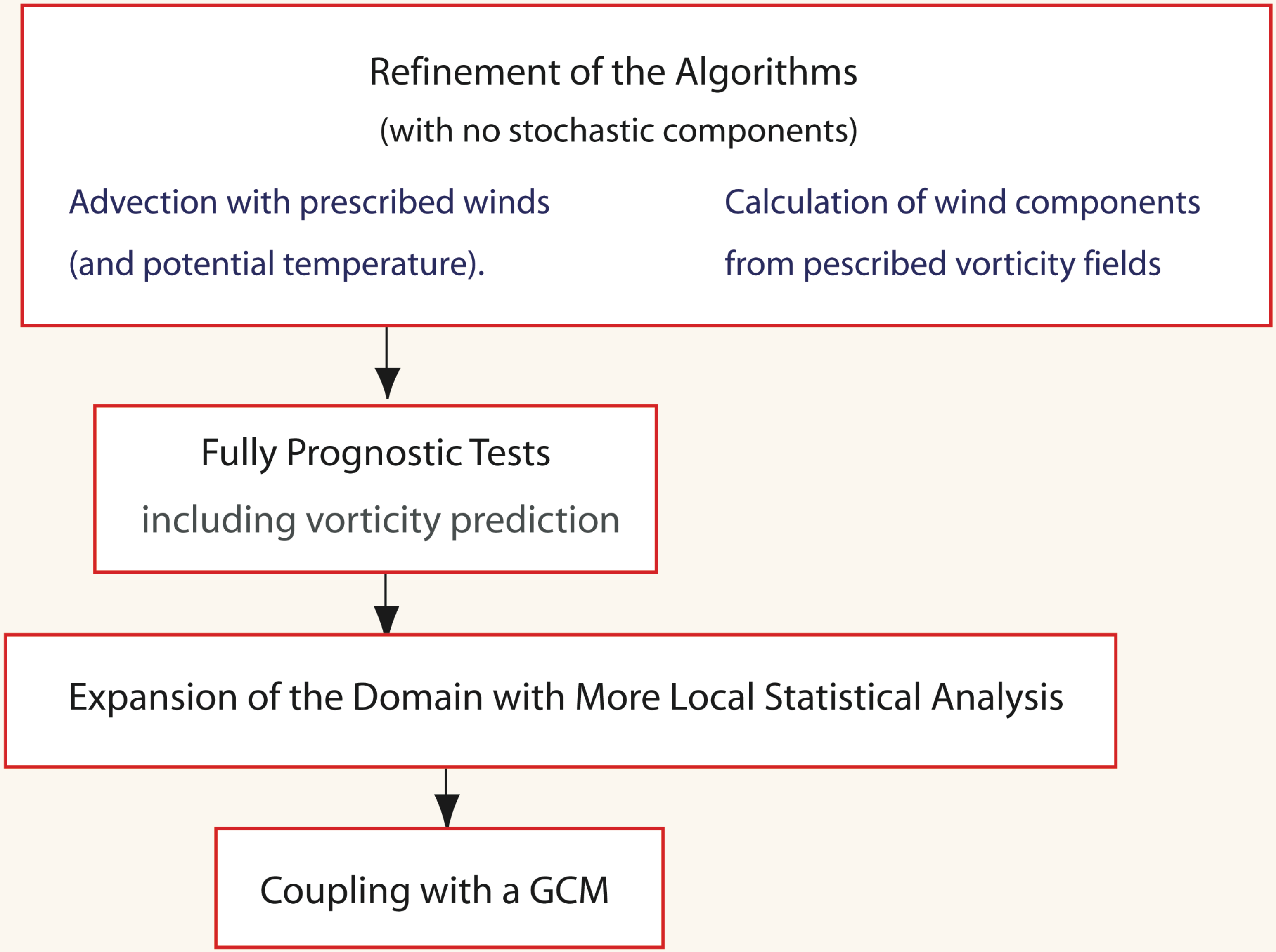


(y-array average)

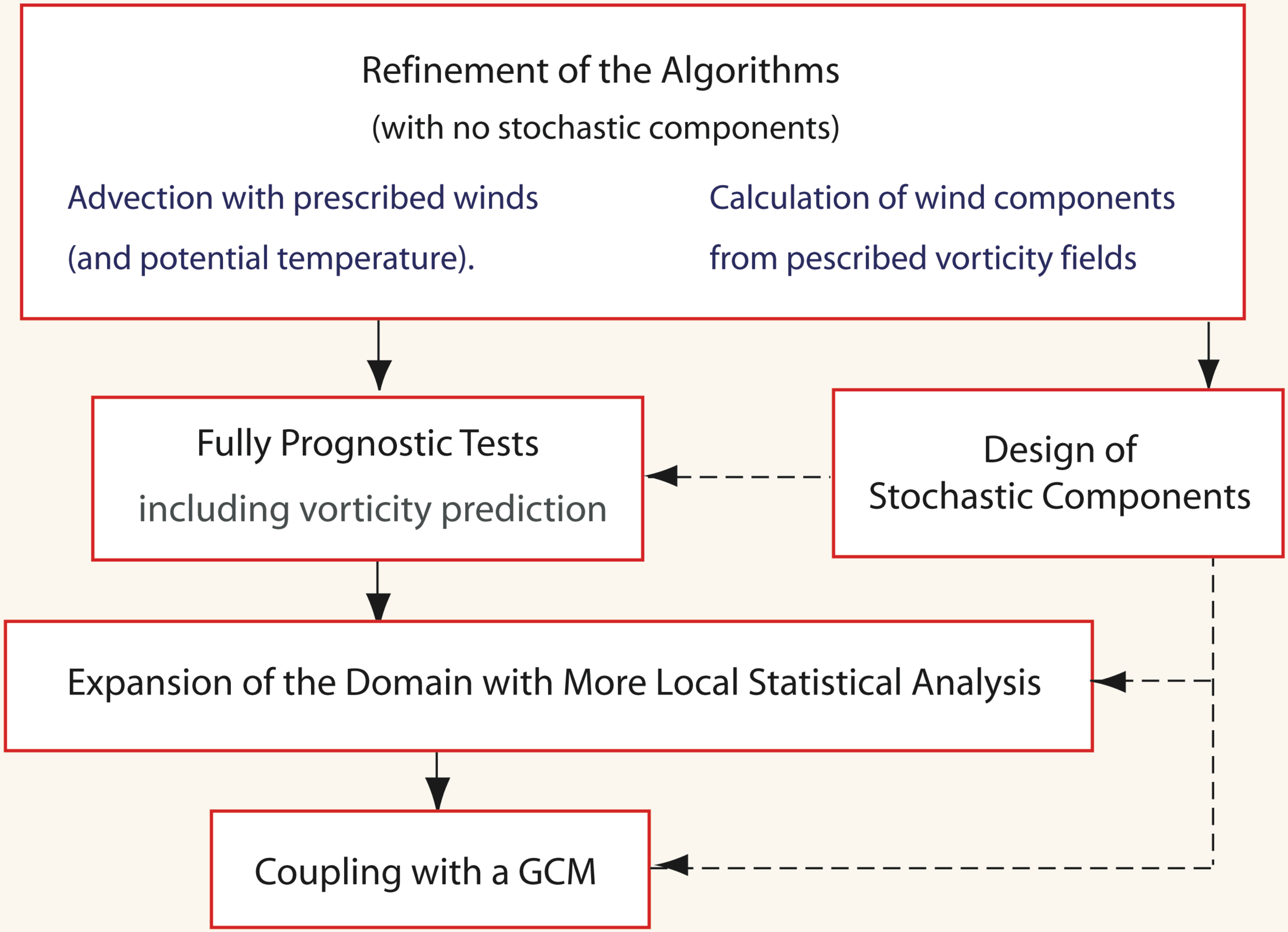




FUTURE PLAN


Refinement of the Algorithms
(with no stochastic components)
Advection with prescribed winds
(and potential temperature).
Calculation of wind components
from pescribed vorticity fields
Fully Prognostic Tests
including vorticity prediction
Expansion of the Domain with More Local Statistical Analysis
Coupling with a GCM

FUTURE PLAN


Refinement of the Algorithms
(with no stochastic components)
Advection with prescribed winds
(and potential temperature).
Calculation of wind components
from pescribed vorticity fields
Fully Prognostic Tests
including vorticity prediction
Design of
Stochastic Components
Expansion of the Domain with More Local Statistical Analysis
Coupling with a GCM