DEVELOPMENT OF THE UNIFIED PARAMETERIZATION

— AN UPDATE —

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BACKGROUND

As far as representation of deep moist convection is concerned,

we are currently using only two kinds of model physics :

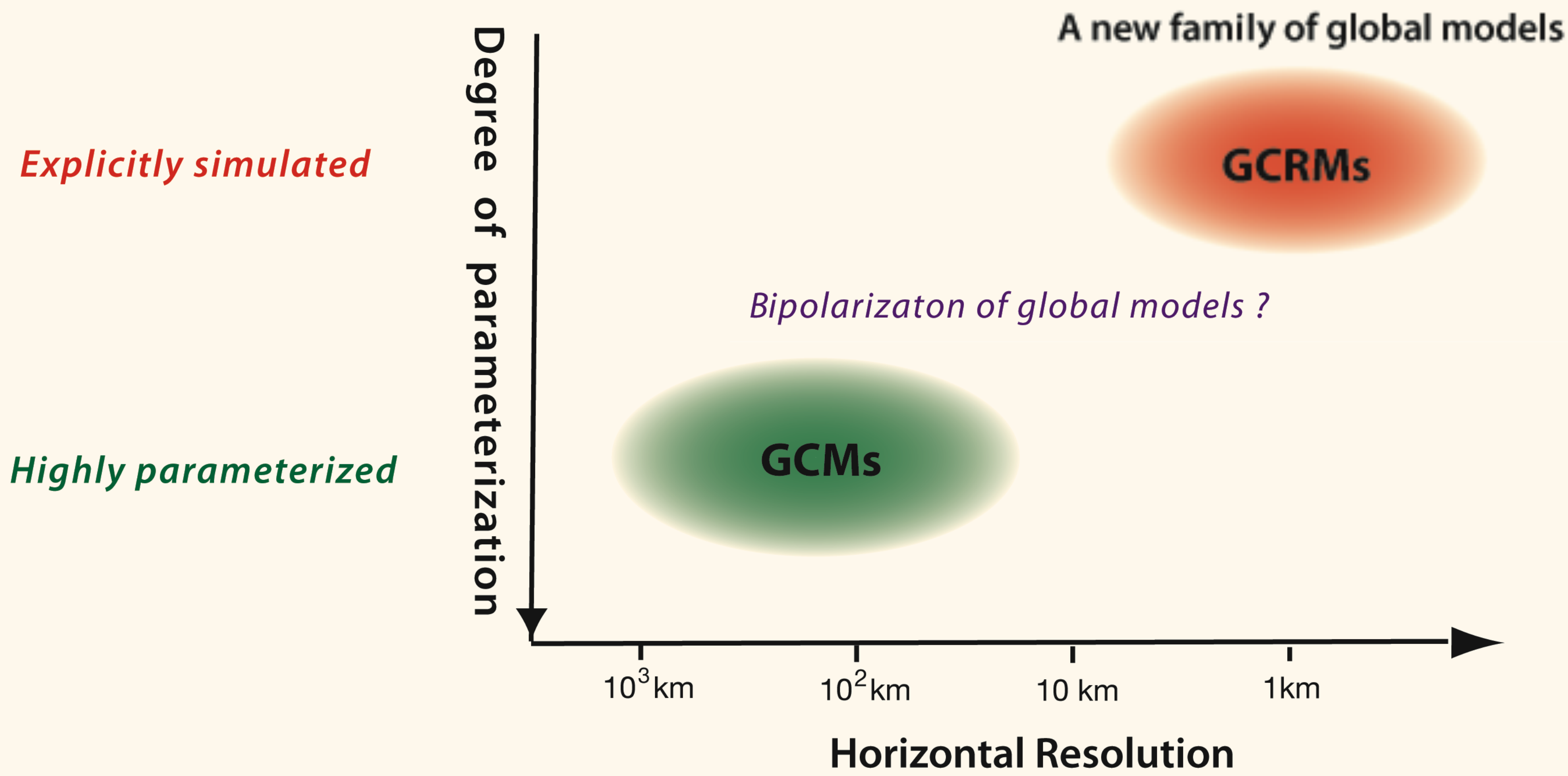
highly parameterized,

and

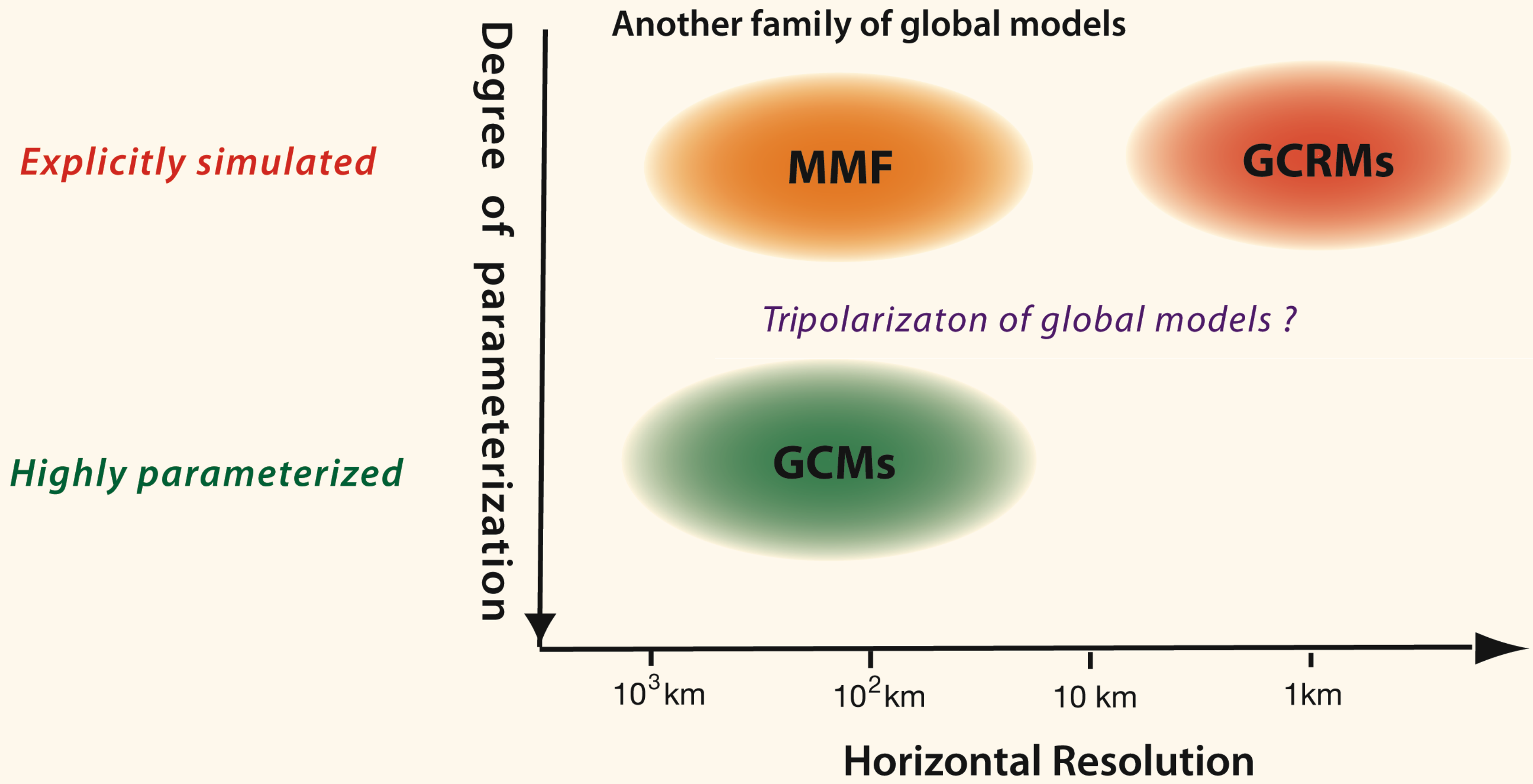
explicitly simulated.

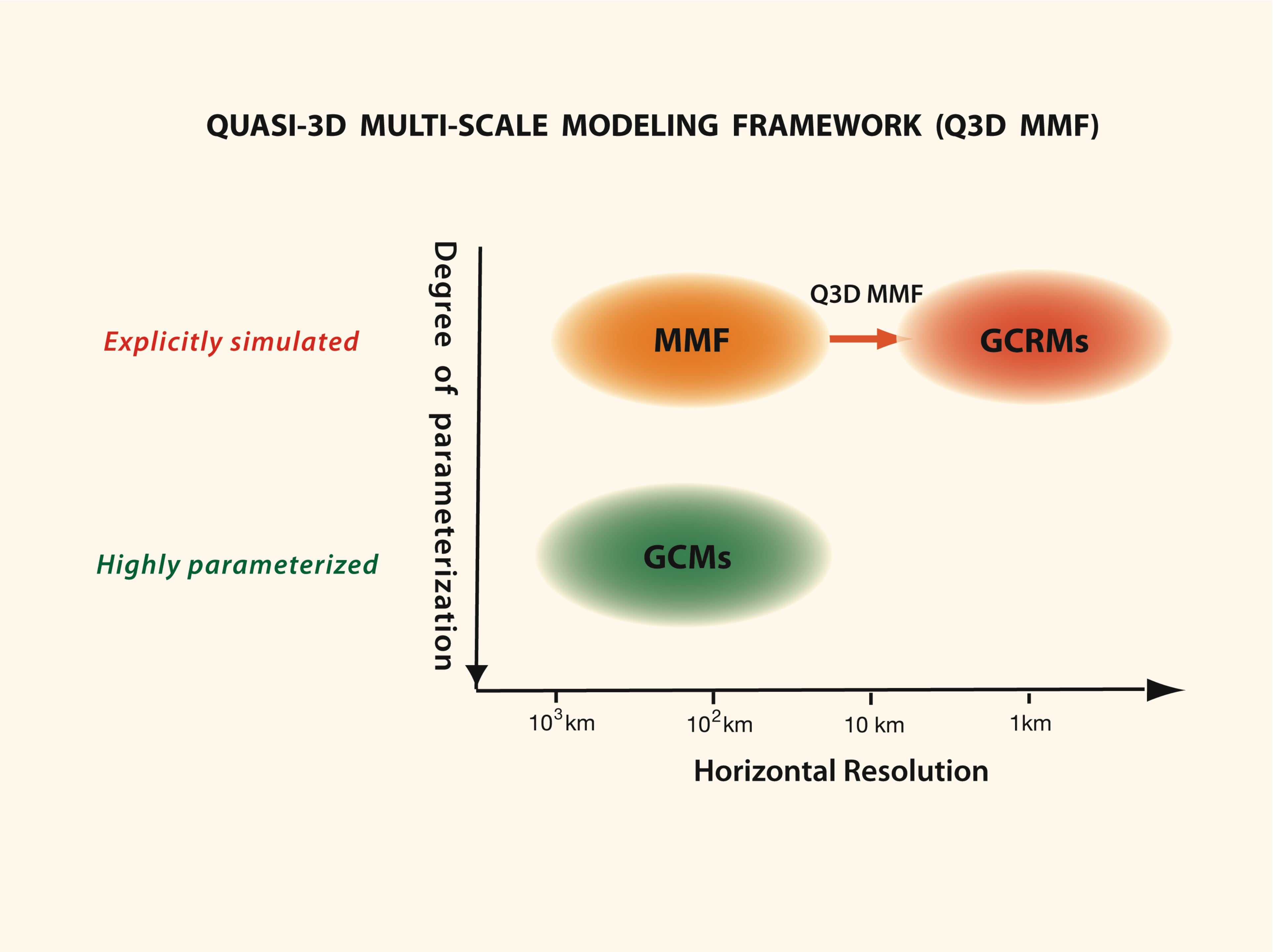
TWO FAMILIES OF ATMOSPHERIC MODELS

(except those models that explicitly simulate turbulence)



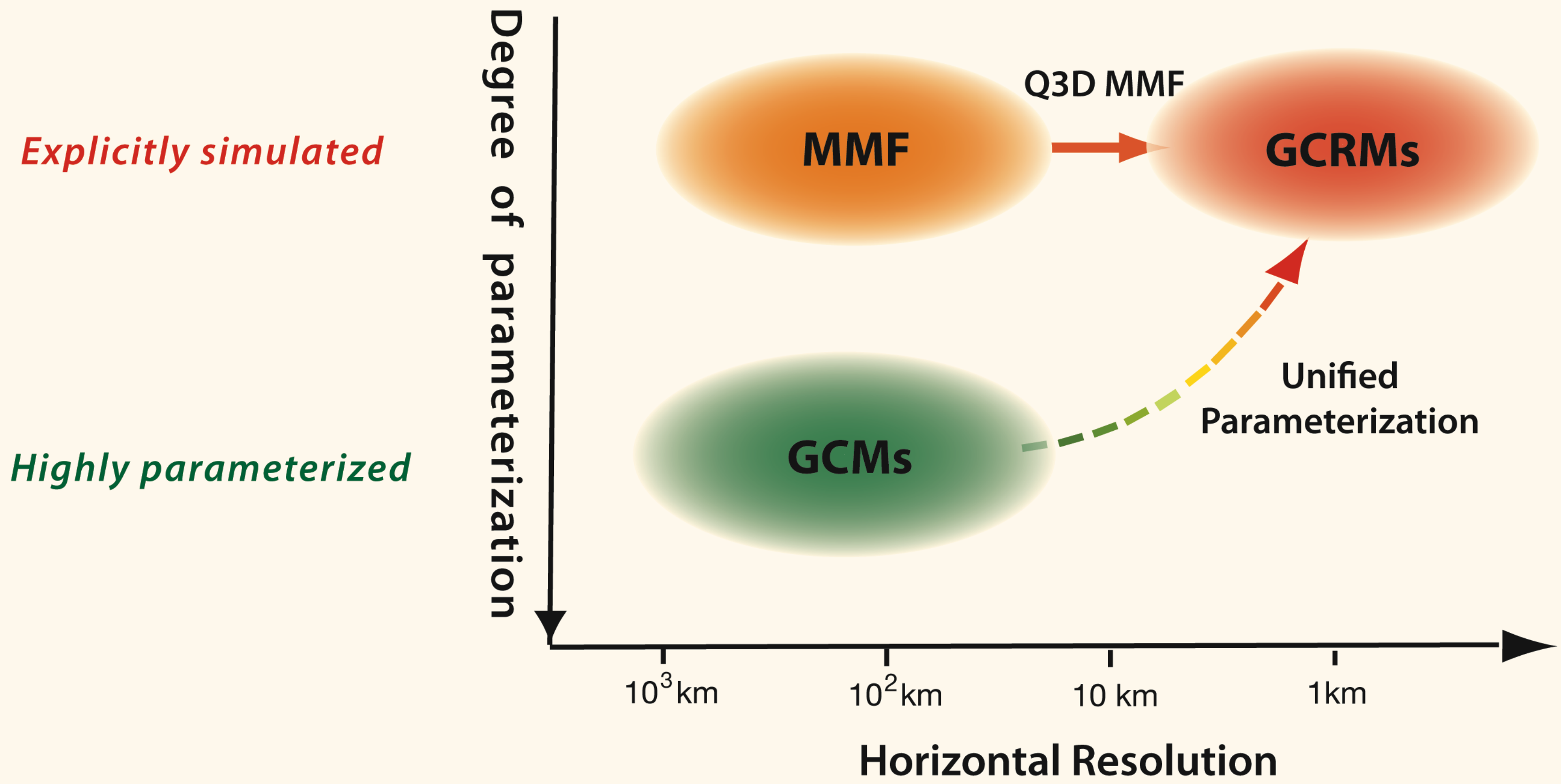
THREE FAMILIES OF ATMOSPHERIC MODELS




QUASI-3D MULTI-SCALE MODELING FRAMEWORK (Q3D MMF)
Explicitly simulated
Highly parameterized
Degree of parameterization
MMF
Q3D MMF
GCRMs
GCMs
10^{3}km
10^{2}km
10 km
1km
Horizontal Resolution

UNIFIED PARAMETERIZATION

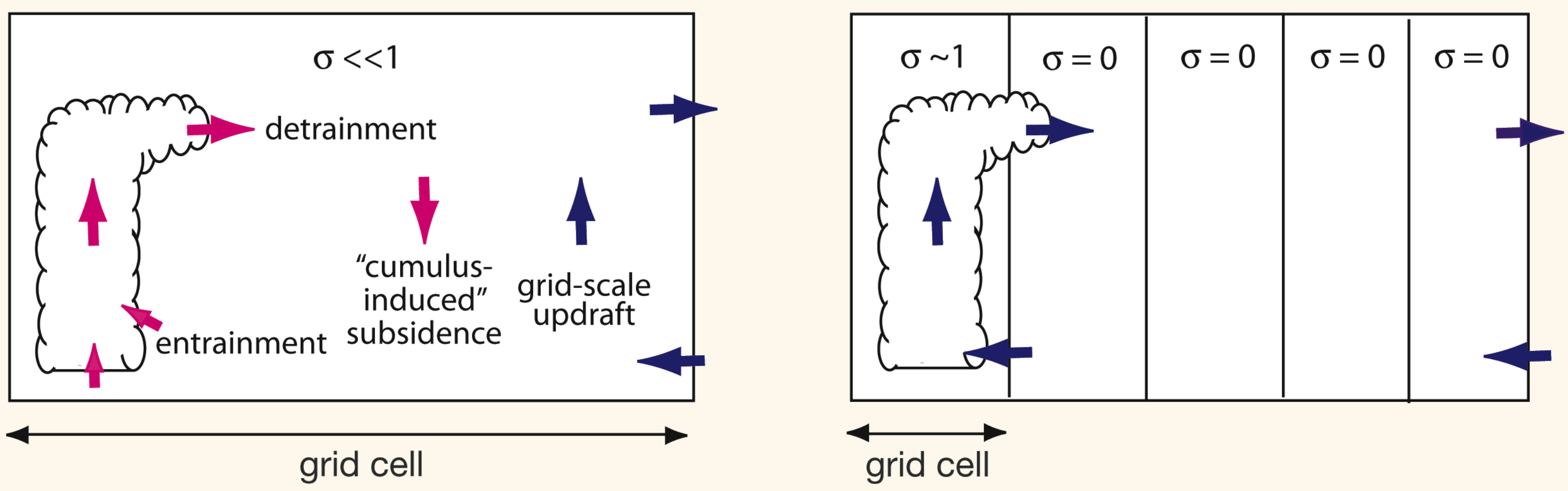
Generalization, not replacement, of cumulus parameterizations in GCMs



OPENING A ROUTE FOR UNFIED PARAMETERIZATION

σ : the fractional area covered by all ***convective*** clouds in a grid cell.

- Conventional parameterizations assume $\sigma \ll 1$, either explicitly or implicitly.
- Then the temperature and water vapor to be predicted are essentially those for the cloud environment.



- But, if cloud occupies the entire cell, there is no "environment" within the cell.

A key to open this route is eliminating the assumption of $\sigma \ll 1$.

CRM SIMULATIONS USED FOR ANALYSIS

To visualize the problem raised above, we have analyzed datasets simulated by a CRM

Model : 3D vorticity equation model of Jung and Arakawa (2008)

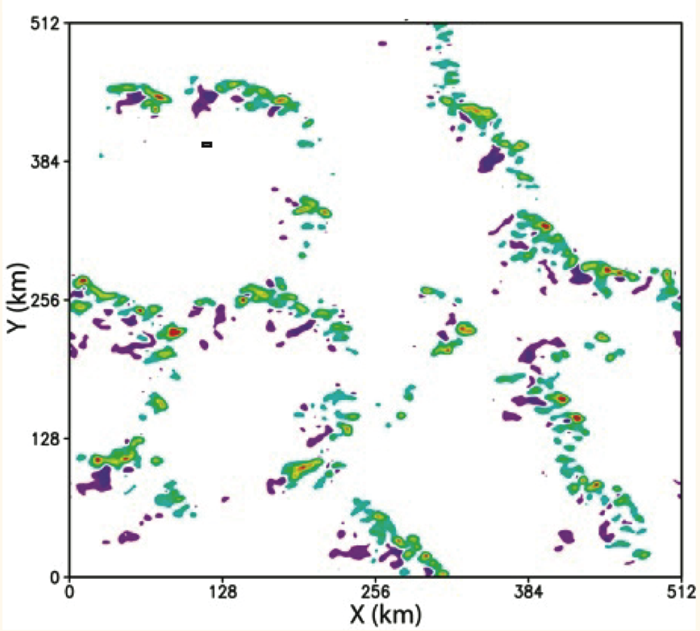
Horizontal domain size : 512 km Horizontal grid size ; 2km

Data used : last 2 hrs of two 24-hr simulations with 20-min intervals

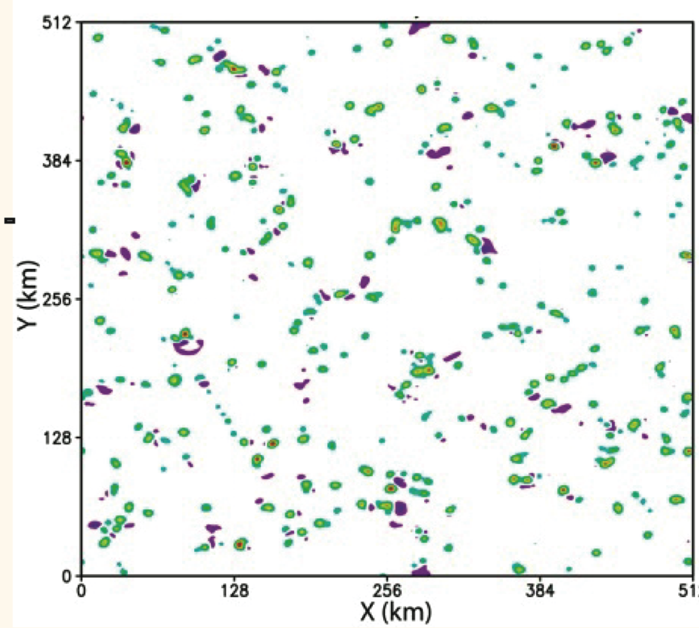
Snapshots of vertical velocity w at 3 km height

w > 0.5 m/s
w < -0.5 m/s

With Shear



Without Shear



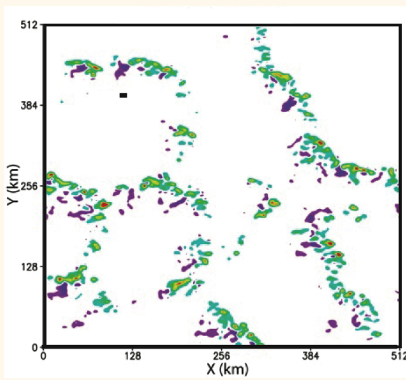
ANALYSIS OF GRID-SIZE DEPENDENT STATISTICS OF THE CRM DATA

The original domain is divided into sub-domains with the same size.

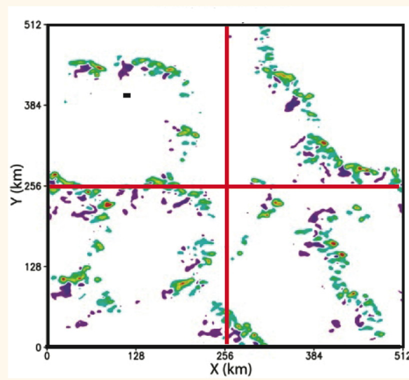
Size of sub-domains : (512 km) $/2^{n-1}$, n=1, 2, 3, 4, . . , 9

Examples

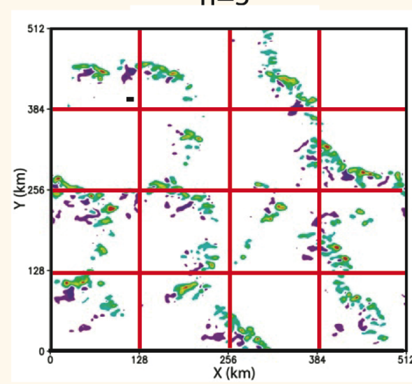
n=1



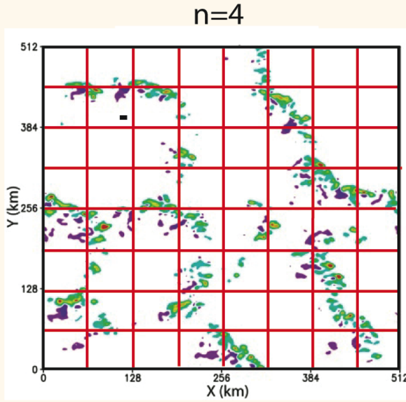
n=2



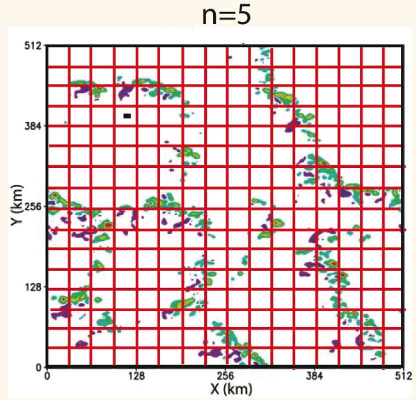
n=3



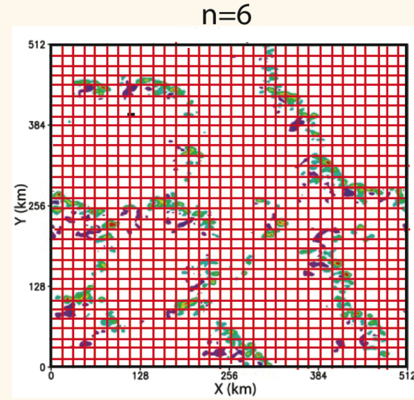
n=4



n=5



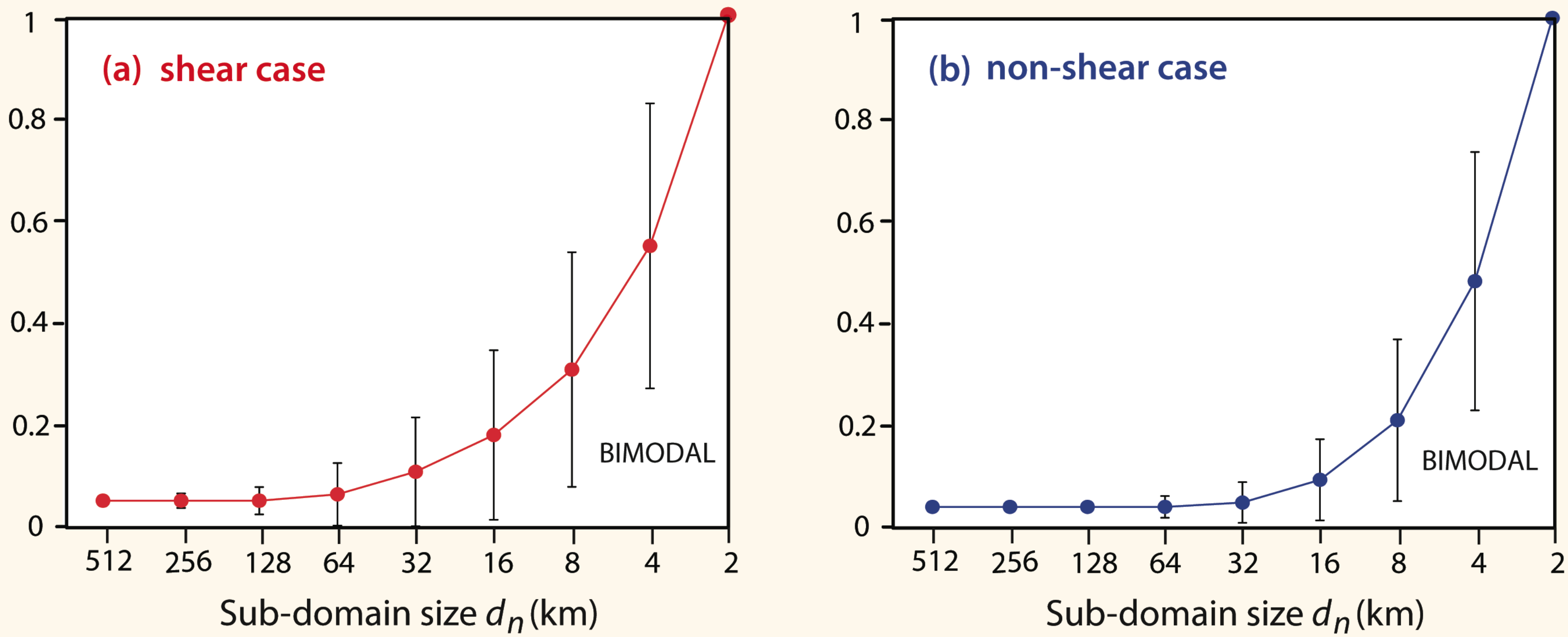
n=6



FRACTIONAL CONVECTVE CLOUD COVER, σ

Measured by the normalized number of grid points that satisfy w>0.5 m/s.

Average over cloud-containing sub-domains at 3 km height



σ<<1 is a good approximation ONLY for large grid sizes.

THE GOAL OF THE UNIFIED PARAMETERIZATION

To formulate the vertical eddy transport

in a way that is applicable to any value of σ including $\sigma = 1$.

EXPRESSIONS OF GRID-CELL AVERAGES

$\overline{(\ )}$: average over the entire grid cell

$(\ )_c$: cloud value $\widetilde{(\ )}$: environment value (not well defined when $\sigma \sim 1$)

At this stage, we neglect the effect of convective-scale downdraft.

For a thermodynamic variable ψ,

$$\overline{\psi} = \sigma \psi_c + (1-\sigma)\widetilde{\psi}$$

$$\overline{w} = \sigma w_c + (1-\sigma)\widetilde{w}$$

$$\overline{w\psi} = \sigma w_c \psi_c + (1-\sigma)\widetilde{w}\widetilde{\psi}$$

Elimination of $\widetilde{\psi}$ and $\widetilde{w}$ →

Vertical eddy transport of ψ:

$$\overline{w\psi} - \overline{w}\,\overline{\psi} = \frac{\sigma}{1-\sigma}\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)$$

MASS-FLUX REPRESENTATION

Vertical eddy transport of ψ :

$$\overline{w\psi} - \overline{w}\,\overline{\psi} = \frac{\sigma}{1-\sigma}\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)$$

In the limit as $\sigma \to 0$ with finite σw_c ,

$$\overline{w\psi} - \overline{w}\,\overline{\psi} \to M_c\left(\psi_c - \overline{\psi}\right), \text{ where } M_c \equiv \rho\sigma w_c .$$

Thus the separation of σw_c to σ and w_c is not necessary as far as the eddy transport is concerned.

In the unified parameterization, σ and w_c must be determined separately.

REQUIREMENT FOR CONVERGENCE TO AN EXPLCT SIMULATION

$$\lim_{\sigma \to 1}\left(w_c - \overline{w}\right) = 0, \ \lim_{\sigma \to 1}\left(\psi_c - \overline{\psi}\right) = 0$$

This indicates that $\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)$ is of the order of $(1-\sigma)^2$ (or higher).

The simplest choice :

$$\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right) = (1-\sigma)^2\left[\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)\right]^*$$

$[\ \ ]^*$: Value expected when σ<<1 detrmined by a non-interactive plume model

With $\overline{w\psi} - \overline{w}\,\overline{\psi} = \dfrac{\sigma}{1-\sigma}\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)$,

$$\overline{w\psi} - \overline{w}\,\overline{\psi} = \sigma(1-\sigma)\left[\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)\right]^*$$

PARTIAL EVALUATION OF THE UNIFIED PARAMETERIZATION

Evaluation of the structure of the unified parameterization

in a way independent of particular choices of a non-intractive plume model

and a closure assumption to determine σ.

We take water vapor mixing ratio q as an example of ψ.

TEST 1

$$\overline{w\psi} - \overline{w}\,\overline{\psi} = \sigma(1-\sigma)\left[\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)\right]^*$$

Since $\left[\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)\right]^*$ is independent of σ,

$\overline{w\psi} - \overline{w}\,\overline{\psi}$ must be correlated with $\sigma(1-\sigma)$.

CORRELATION COEFFICIENTS

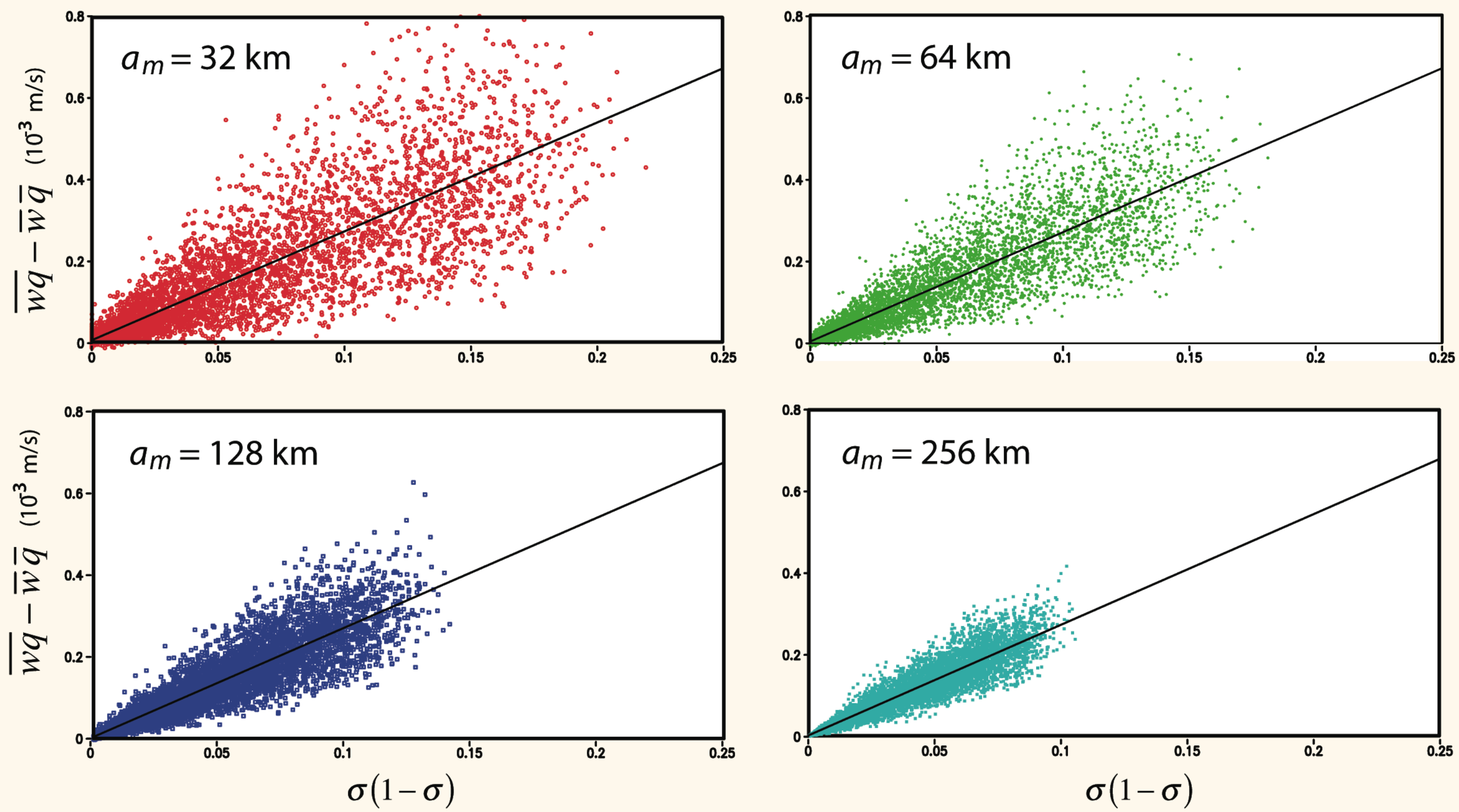
BETWEEN DIAGNOSED $\overline{wq} - \overline{w}\,\overline{q}$ AND $\sigma(1-\sigma)$

SHEAR CASE		Sub-domain size d_n used for diagnosis						
		256 km	128 km	64 km	32 km	16 km	8 km	4 km
Averaging* size a_m	4 km							0.46
	8 km						0.62	0.60
	16 km					0.76	0.77	0.65
	32 km				0.88	0.87	0.81	0.70
	64 km			0.94	0.94	0.90	0.84	0.75
	128 km		0.93	0.93	0.94	0.91	0.87	0.80
	256 km	0.94	0.95	0.92	0.93	0.92	0.89	0.83

* Horizontal averaging applied before correlatioin is taken

SCATTER PLOTS OF $\overline{wq} - \bar{w}\,\bar{q}$ AGAINST $\sigma(1-\sigma)$ WITH $d_n = 16$ km

FOR VARIOUS AVERAGING SIZES a_m



- The ratio of the scatter to the mean value does not significntly depend on sigma.
- The ratio depends on the averaging length as expected.

PARTIAL EVALUATION OF THE UNIFIED PARAMETERIZATION

TEST 2

We made the choice : $$\left(w_c - \overline{w}\right)\left(q_c - \overline{q}\right) = \left(1-\sigma\right)^2 \left[\left(w_c - \overline{w}\right)\left(q_c - \overline{q}\right)\right]^* \qquad (1)$$

Then $$\overline{wq} - \overline{w}\,\overline{q} = \sigma\left(1-\sigma\right)\left[\left(w_c - \overline{w}\right)\left(q_c - \overline{q}\right)\right]^* \qquad (2)$$

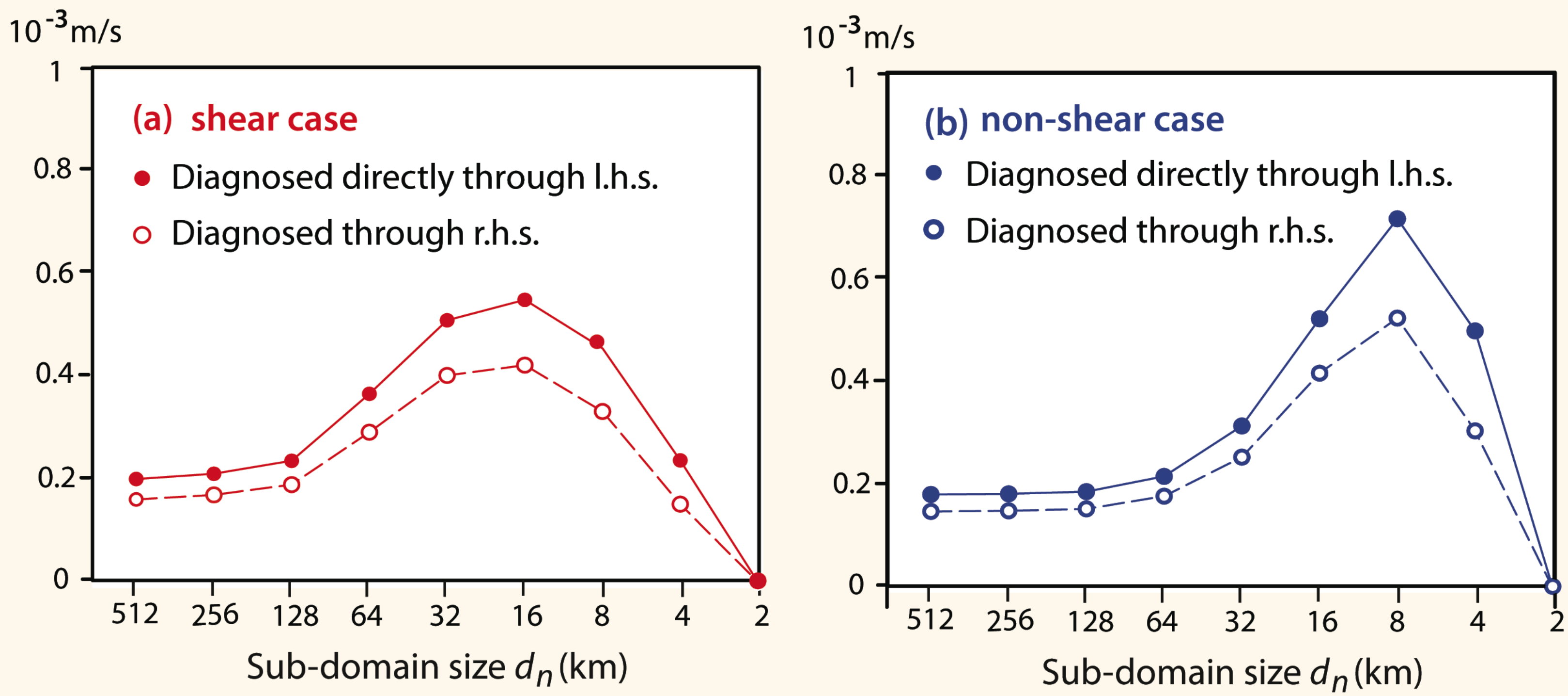
< > : Average over all sub-domains of the same size with weight σ.

From <(1)> and <(2)>, $$\left\langle \overline{wq} - \overline{w}\,\overline{q} \right\rangle = \frac{\left\langle \sigma\left(1-\sigma\right)\right\rangle}{\left\langle \left(1-\sigma\right)^2 \right\rangle} \left\langle \left(w_c - \overline{w}\right)\left(q_c - \overline{q}\right)\right\rangle$$

Here the difference of $\left[\left(w_c - \overline{w}\right)\left(\psi_c - \overline{\psi}\right)\right]^*$ between the sub-domains has been ignored.

WEIGHTED AVERAGE OF $\overline{wq} - \overline{w}\,\overline{q}$ OVER SUB-DOMAINS

$$\left\langle \overline{wq} - \overline{w}\,\overline{q} \right\rangle = \frac{\left\langle \sigma(1-\sigma) \right\rangle}{\left\langle (1-\sigma)^2 \right\rangle} \left\langle \left(w_c - \overline{w}\right)\left(q_c - \overline{q}\right) \right\rangle$$



DETERMINATION OF σ

$\left(\overline{wh}-\bar{w}\bar{h}\right)_{adj}$: $\left(\overline{wh}-\bar{w}\bar{h}\right)$ calculated by a conventional parameterization

using $\left(w_c-\bar{w}\right)\left(h_c-\bar{h}\right)=\left[\left(w_c-\bar{w}\right)\left(\psi_c-\bar{h}\right)\right]^*$ Non-interactive plume model

For $\left(\overline{wh}-\bar{w}\bar{h}\right)_{adj}$ and $\left[\left(w_c-\bar{w}\right)\left(h_c-\bar{h}\right)\right]^*$ to satisfy $\overline{wh}-\bar{w}\bar{h}=\frac{\sigma}{1-\sigma}\left(w_c-\bar{w}\right)\left(\psi_c-\bar{h}\right)$,

$$\sigma=\frac{\left(\overline{wh}-\bar{w}\bar{h}\right)_{adj}}{\left(\overline{wh}-\bar{w}\bar{h}\right)_{adj}+\left[\left(w_c-\bar{w}\right)\left(\psi_c-\bar{h}\right)\right]^*}$$

This σ automatically satisfies

$0\le\sigma\le1$ including

$\sigma\to1$ as $\left(\overline{w\psi}-\bar{w}\bar{\psi}\right)_{\mathrm{adj}}\to\infty$.

The unified parameterization uses this σ for $\left(w_c-\bar{w}\right)\left(h_c-\bar{h}\right)=\underline{(1-\sigma)}^2\left[\left(w_c-\bar{w}\right)\left(\psi_c-\bar{h}\right)\right]^*$

Correspondingly, $$\overline{wh}-\bar{w}\bar{h}=\underline{(1-\sigma)}^2\left(\overline{wh}-\bar{w}\bar{h}\right)_{adj}$$ (Relaxed adjustment)

SUMMARY AND CONCLUSION

- GCMs and GCRMs should be unified so that we can freely choose a resolution without changing formulation of model physics.

- The unified parameterization can achieve the unification through a relatively minor modification of the existing parameterizations.

- The third approach that bridges conventional GCMs and the Q3D MMF can also be constructed.