Coupling the GCM and CRM Components of MMF

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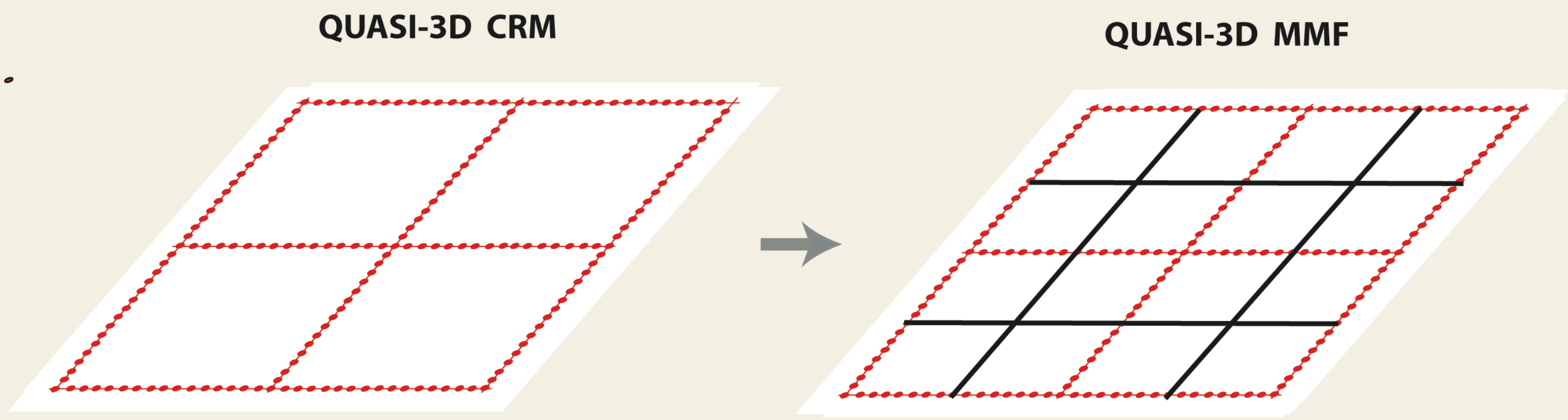
A concluding remark of our presentation at the last meeting :

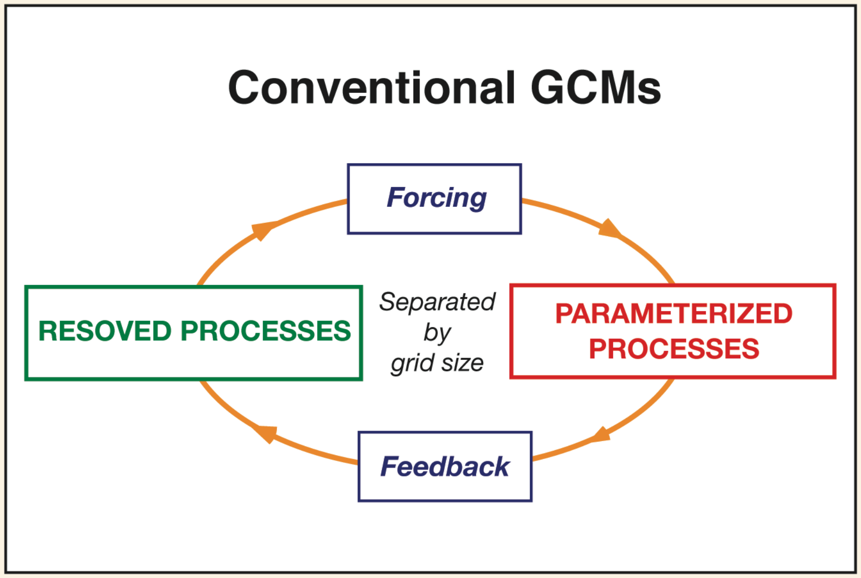
" It seems that we are approaching the limit of the "piece by piece" test strategy and we should start to couple the Q3D CRM with a GCM soon."



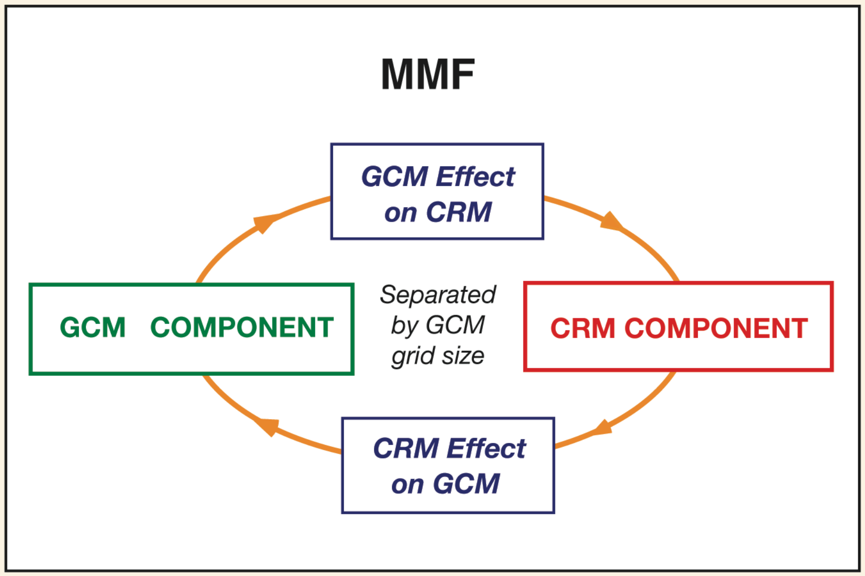
We realize, however, that formulation of the coupling is a big problem regardless of the dimensionality of the CRM.

THE PROBLEM OF COUPLING THE TWO COMPONENTS OF MMF

The basic structure of conventional GCMs



MMF inherits this basic structure

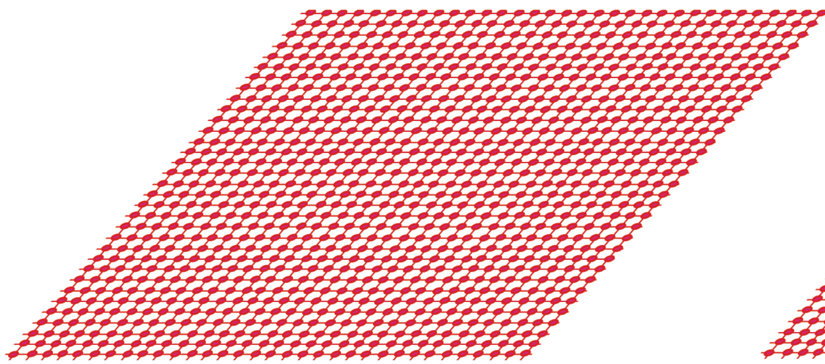


The classical closure problem of cumulus parameterization is now replaced by the problem of formulating the coupling of the two components.

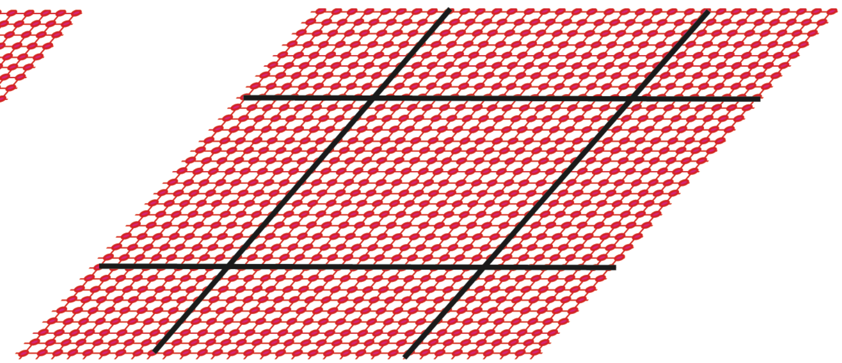
To study the coupling problem in a way independent of the dimensionality,

we use

3D CRM (for benchmark simulation)



3D MMF (for testing of coupling)



We formulate the couplimg of the GCM and CRM components through prognostic variables of the GCM and the corresponding subset of CRM prognostic variables.

Let q be one of such variables.

GCM $$\frac{\partial q_G}{\partial t} = S_G + \left(\frac{\partial q_G}{\partial t}\right)_{CRM}$$

CRM $$\frac{\partial q_C}{\partial t} = S_C + \left(\frac{\partial q_C}{\partial t}\right)_{GCM}$$

S : the sum of sourc/sink due to physics, advection, dynamics

$$\frac{\partial}{\partial t}\left(q_G - \langle q_C \rangle\right) = S_G - \langle S_C \rangle + \left(\frac{\partial q_G}{\partial t}\right)_{CRM} - \left(\frac{\partial q_C}{\partial t}\right)_{GCM}$$

< > : horizontal average over the GCM grid box

Approach A : Explicit Formulation as Forcing and Feedback

- Resembles the (original) Arakawa-Schubert type parameterization
- Roughly corresponds to the approaches followed by

  Grabowski and Smolarkiwiecz (1999) for thermodynamic variables, and

  Khairoutdinov and Randall (2001) for both thermodynamic variables and momentum

$$\frac{\partial q_G}{\partial t} = S_G + \underbrace{< S_C >}_{\text{feedback}} \qquad \frac{\partial q_C}{\partial t} = S_C + \underbrace{\hat{S}_G}_{\text{forcing}}$$

$\left(\hat{\ }\right)$: interpolated or uniformly given

S_G and S_C must be mutually exclusive to avoid double counting

Then, $$\frac{\partial}{\partial t}\left(q_G - < q_C >\right) \simeq 0$$ since $< \hat{q}_G > \simeq q_G$

- *Thus prediction of q_G is entirely done by the CRM.*
- *The copling is so rigid that If the GCM is in a quasi-equilibrium, the CRM is also in a quasi-equilibrium.*

Approach B: Formulation as Mutual Adjustments

- Resembles the Betts-Miller parameterization
- Roughly corresponds to the approach followed by Grabowski and Smolarkiwiecz (1999) for momentum.

$$\frac{\partial q_G}{\partial t} = S_G - \frac{1}{\tau_G}(q_G - < q_C >) \qquad \frac{\partial q_C}{\partial t} = S_C - \frac{1}{\tau_C}(q_C - \hat{q}_G)$$

No double counting problem

Then,

$$\frac{\partial}{\partial t}(q_G - < q_C >) = S_G - < S_C > - \left(\frac{1}{\tau_G} + \frac{1}{\tau_C}\right)(q_G - < q_C >)$$

- *The stationary solution of the last equation indicates that* q_G *and* $< q_C >$ *are not compatible.*
- *Since* q_C *tends to be adjusted to* $\hat{q}_G$ *,* q_C *may be excessively damped.*
- *An idealized model for the interactin between cloud and large scales shows that convective activity is under-predicted when* $\tau_G < \tau_C$ *and over-pedicted when* $\tau_G > \tau_C$.

Approach C   Hybrid Approach

Principles followed :

I. *The GCM and CRM components should be compatible in the sense* $q_G \approx < q_C >$ *at least for time scales longer than the physical adjustment time scale.*

$$\frac{\partial}{\partial t}(q_G - < q_C >) = -\frac{1}{\tau}(q_G - < q_C >)$$

Similar to Approach B

II. *The CRM should recognize the GCM through large-scale forcing without delay while the adjustment of the GCM variabkes by the CRM may require a finite time.*

$$\left(\frac{\partial q_C}{\partial t}\right)_{GGM} = \hat{S}_G$$

Same as in Approach A

Then,

$$\frac{\partial q_G}{\partial t} = < S_C > + < \hat{S}_G > - \frac{1}{\tau}(q_G - < q_C >) \qquad \frac{\partial q_C}{\partial t} = S_C + \hat{S}_G$$

Resuces to Approch A in the limit $\tau \rightarrow 0$.