PROGRESS TOWARDS A QUASI-3D MMF

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First CMMAP Team Meeting
Fort Collins, August 15-17, 2006
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

MODELS RESOLUTION

GCM

CRM

LES
THREE FAMILIES OF MODELS

MODEL PHYSICS

Degree of parameterization

MODEL RESOLUTION

10^3 km  10^2 km  10 km  1 km  10^2 m

GCM  LES  CRM

Ideally, but…
TYPICAL VERTICAL PROFILES OF MOIST STATIC ENERGY SOURCE
DUE TO DEEP CONVECTION

Required Source for GCMs
as indicated by observed L-S budgets

Real Source
As expected from local cloud microphysics

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**
Uses CRM physics while using a typical GCM resolution for the mother model.
Necessary to maintain the diversity of climate studies.

Uses CRM physics while using a typical GCM resolution for the mother model.
CRM physics can remain valid.

Number of independent grid points:
\[ n^2 = 1024 \]

Standard way of decreasing number of grid points

CRM physics rapidly deteriorates.
Resolution is partly used to "sense" the meso- and cloud-scales.

Resolution is entirely in the synoptic-scale range.

WAVENUMBER SPACE

- Synoptic scale
- Meso & cloud scales
This highly anisotropic grid is not appropriate for large-scale dynamics.
**QUASI-3D MMF**

- GCM grid box
- GCM scalar point

*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

\[ q = \bar{q} + q', \]

where

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

\( q' \): Deviation of \( q \) from \( \bar{q} \), 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 $q'^1 = 0$

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

\[
\Delta_j q' = a_1 + b_1 \Delta_i q' + f_1
\]

- Estimated first-order difference in the normal direction
- Predicted first-order difference in the tangential direction
- 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.

\[ \delta_j^2 q' = a_2 + b_2 \delta_i^2 q' + f_2 \]

- \( \delta_j^2 q' \): Estimated second-order difference in the normal direction
- \( a_2 \): Predicted first-order difference in the tangential direction
- \( f_2 \): A stochastic function

with \( b_2 \geq 1 \)
\[ \Delta_j \hat{q}' = a_1 + b_1 \Delta_i \hat{q}' + f_1 \]

\[ \delta^2_i \hat{q}' = a_2 + b_2 \delta^2_i \hat{q}' + f_2 \]

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.
(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 (mimicking the relaxation method).

- The second-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).
Calculation of wind components from prescribed vorticity fields

Tracer
Different phases of water with physics

The results of these tests are encouraging and we are almost ready to proceed to fully prognostic tests.
\[ q'_{c}^2 \]

(x-array average)

Q3D (null estimate)  
Q3D  
CONTROL (3D)

(y-array average)

Q3D (null estimate)  
Q3D  
CONTROL (3D)
FUTURE PLAN

Refinement of the Algorithms
(with no stochastic components)
Advection with prescribed winds (and potential temperature).
Calculation of wind components from prescribed 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
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Design of Stochastic Components

Expansion of the Domain with More Local Statistical Analysis

Coupling with a GCM