Progress in the Development of Quasi-3D Multiscale Modeling Framework as a Physics Option in CAM-SE

Joon-Hee Jung, Celal S. Konor, David A. Randall,
Department of Atmospheric Sciences, Colorado State University, USA

Peter Lauritzen, and Steve Goldhaber
National Center for Atmospheric Research, Boulder, Colorado, USA

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Quasi-3D Multiscale Modeling Framework

- CRMs in GCM grid columns are seamlessly connected;
- Two segments of CRMs perpendicularly pass each other (but don’t intersect) at the center of each GCM cell;
- CRMs are three-dimensional, although covering only channel-like domains.

**Q3D MMF**

- GCM grid cell
- GCM grid
- CRM grid
- CRM ghost grid
Quasi-3D Multiscale Modeling Framework

- CRMs in GCM grid columns are seamlessly connected;
- Two segments of CRMs perpendicularly pass each other (but don’t intersect) at the center of each GCM cell;
- CRMs are three-dimensional, although covering only channel-like domains.

Cloud systems travel freely along the CRM channels;
Surface orography can be resolved by the CRMs;
Subgrid-scale vertical momentum transport can be directly simulated.
Development of a Global Q3D MMF

A global version of Q3D MMF has been created.

- **GCM component**: *dynamical core based on the cubed sphere grid*
  
  - Quadrilateral geometry allows a straightforward extension to the sphere of our limited-area model based on rectangular Cartesian coordinate.
  
  - Cubed sphere grid has relatively uniform horizontal grid spacings almost everywhere, allowing the CRM channels to be almost uniformly distributed.

- **CRM component**: *the CRM used in the limited-area Q3D MMF*
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**CAM-SE CSLAM dynamical core**

**Vector Vorticity Model**

(CRM developed at CSU/UCLA)
Vector Vorticity Model as a CRM Component of the Q3D MMF

- 3D nonhydrostatic anelastic model;
- The prognostic dynamical variables are vorticity components;
- Pressure gradient force is eliminated from the governing Eqs;
- Vertical velocity is a solution of a 3D elliptic equation;
- CRM-type physics parameterizations are included.
Vector Vorticity Model as a CRM Component of the Q3D MMF

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Suitable for the Q3D MMF

It is convenient to formulate the lateral boundary conditions required by the narrow CRM channels and the lower boundary condition over steep topography.
Implementation of the Vector Vorticity Dynamical Core on Cubed Sphere for Use in the Q3D MMF

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Rotation of a cosine bell along the equator
Following Williamson et al. (1992)
VVM: Barotropic Instability Test (Case 1)

Initial Vorticity

Similar to Galewsky et al. (2004)
**VVM: Barotropic Instability Test (Case 1)**

**Initial Vorticity**

Similar to Galewsky et al. (2004)

\[ t = 168 \text{ h} \]

\[ \text{dx} = \text{dy} \sim 100 \text{ km} \]

\[ \text{dx} = \text{dy} \sim 6 \text{ km} \]
VVM: Barotropic Instability Test (Case 2)

Initial Vorticity

$t = 120 \text{ h}$

Longitude-latitude grids \hspace{1cm} dx = dy \sim 100 \text{ km}

Cubed-sphere grids
**VVM: Barotropic Instability Test (Case 2)**

Initial Vorticity

$t = 120 \text{ h}$

**dx = dy \sim 100 \text{ km}**

Longitude-latitude grids

Cubed-sphere grids

**dx = dy \sim 6 \text{ km}**

Longitude-latitude grids

Cubed-sphere grids

Legend:
-16 -14 -12 -10 -8 -6 -4 -2 2 4 6 8 10 12 14 16 $10^{-5}$ (s$^{-1}$)
VVM: Baroclinic Instability Test

Idealized setting: $f = 2\Omega \sin(\varphi + \pi/4)$

Zonally Uniform Initial State

Initial Perturbation on Potential Temperature
VVM: Baroclinic Instability Test

Idealized setting: \( f = 2\Omega \sin(\varphi + \pi/4) \)

Zonally Uniform Initial State

Initial Perturbation on Potential Temperature

\( t = 288 \, h \)

Longitude-latitude grids

Cubed-sphere grids

\( dx = dy \sim 100 \, \text{km} \)

\( dx = dy \sim 12 \, \text{km} \)
Horizontal Grid Structure of the Q3D MMF

Two Grid Systems

Low-resolution GCM grid

High-resolution CRM grid

The CRMs are coupled with the physics grids.
For communication, horizontal interpolation and cell-average are needed.
Example of Horizontal Grid Distribution

\[ N_{phy} = 3, \; N_e = 5, \; N_c = 25 \]
\( (d_{GCM} \sim 660 \text{ km}, \; d_{CRM} \sim 26 \text{ km}) \)

**CRM grid channels**

\[ \text{# of physics-grid columns on the sphere } = (N_{phy} \times N_e)^2 \times 6 = 1,350 \]
\[ \text{# of CRM-grid columns on the sphere } = (\text{# of physics-grid columns}) \times N_c \times 2 = 67,500 \]
**Example of Horizontal Grid Distribution**

- **CRM grid channels**
  - $N_{phy} = 3$, $N_{e} = 5$, $N_{c} = 25$
  - ($d_{x_{GCM}} \sim 660 \text{ km}$, $d_{x_{CRM}} \sim 26 \text{ km}$)

  
  
  # of physics-grid columns on the sphere = ($N_{phy} \times N_{e}$)$^2 \times 6 = 1,350$
  
  # of CRM-grid columns on the sphere = (# of physics-grid columns) $\times N_{c} \times 2 = 67,500$
  
  ($d_{x_{GCM}} \sim 100 \text{ km}$, $d_{x_{CRM}} \sim 4 \text{ km}$)  \[ \frac{48,600}{2,430,000} \]
Vertical Grid Structure of the Q3D MMF

For communication, vertical interpolation is needed.
**Q3D MMF Computation Algorithm**

Similar to the coupling approach of CAM-SE

<table>
<thead>
<tr>
<th>PRE-CRM Procedures</th>
<th>CRM PREDICTION</th>
<th>POST-CRM Procedures</th>
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<tbody>
<tr>
<td>Generation of data on physics grids</td>
<td><strong>“physics”</strong></td>
<td>Distribution of CRM feedbacks to Dycore points</td>
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<td>vGCM communications (moving data to channel decomposition)</td>
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<td>Calculation of mean CRM feedbacks (physics tendencies)</td>
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<td>Interpolation of vGCM data to CRM points</td>
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<td>CRM COMPUTE</td>
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</table>

**Hybrid Dynamics/Physics coupling**
Communication between Dycore & CRMs

**GCM GLL grid**

Two model components are coupled at every GCM time step.

**“Interface”**

Output from CRM:
- Eddy transport & diabatic effects
  (cell averages)

Input to CRM:
- GCM-scale solutions interpolated to CRM grids

**GCM physics grid**

**CRM grid**
Test of Q3D MMF Interfaces

The GCM-scale input data are distributed to CRM grids through horizontal and vertical interpolations and gathered back to physics grids without performing the CRM-prediction.

$Q_{v_{in}}$  $k = 15$  $Q_{v_{out}}$

$k = 32$ (Lowest model layer)
Short-Term Simulation of the Q3D MMF

Surface Pressure

(Lowest model layer)

T

Q_v

Q_r
Short-Term Simulation of the Q3D MMF

Surface Pressure

(Lowest model layer)

T

Qv

Qr

With CRM Feedback (Microphysical effect)
Short-Term Simulation of the Q3D MMF

Surface Pressure

(Lowest model layer)

\( T \)

\( Q_v \)

\( Q_r \)

With CRM Feedback (Microphysical effect)
Summary

A global version of Q3D MMF has been created by coupling the VVM on cubed-sphere grids with the CAM-SE-CSLAM dynamical core (https://svn-ccsm-models.cgd.ucar.edu/cam1/branches/Q3D).

We are making progress in testing and debugging the new global Q3D MMF with short-term simulations.
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A global version of Q3D MMF has been created by coupling the VVM on cubed-sphere grids with the CAM-SE-CSLAM dynamical core ([https://svn-ccsm-models.cgd.ucar.edu/cam1/branches/Q3D](https://svn-ccsm-models.cgd.ucar.edu/cam1/branches/Q3D)).

We are making progress in testing and debugging the new global Q3D MMF with short-term simulations.

We will continue to evaluate and improve the model for its application to long-term simulations.

- Finish up the code development;
- Make improvement to numerical methods and parameterizations;
- Speed up the computing time (hybrid MPI/OpenMP)