Research Objective 1:

Development of a Q3D MMF

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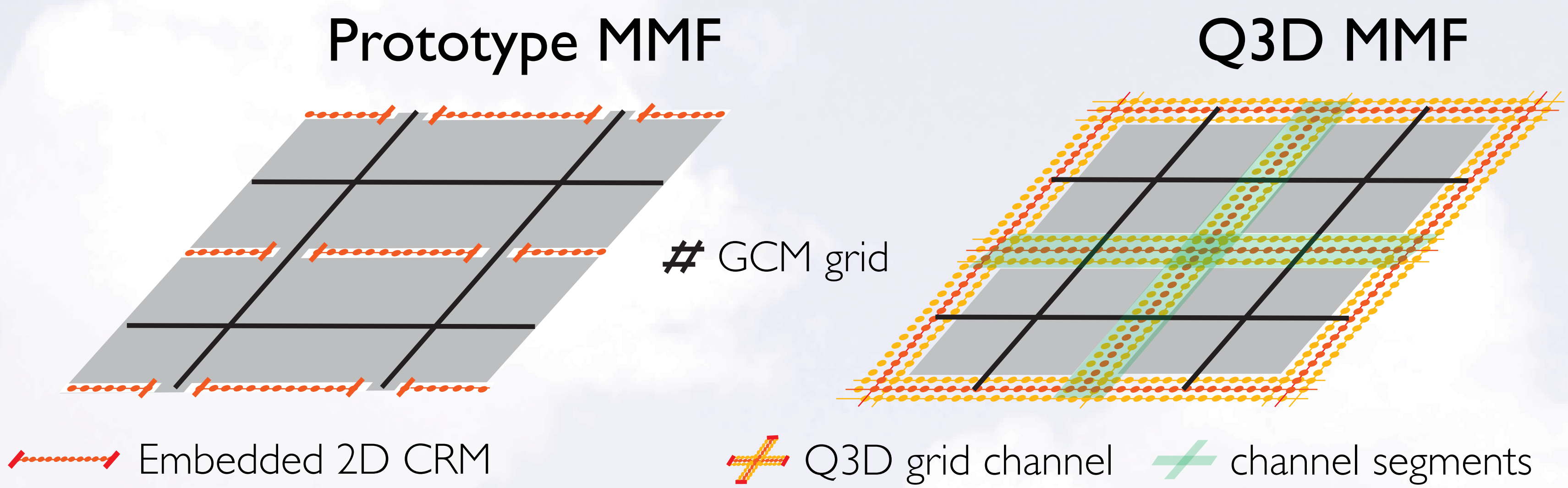
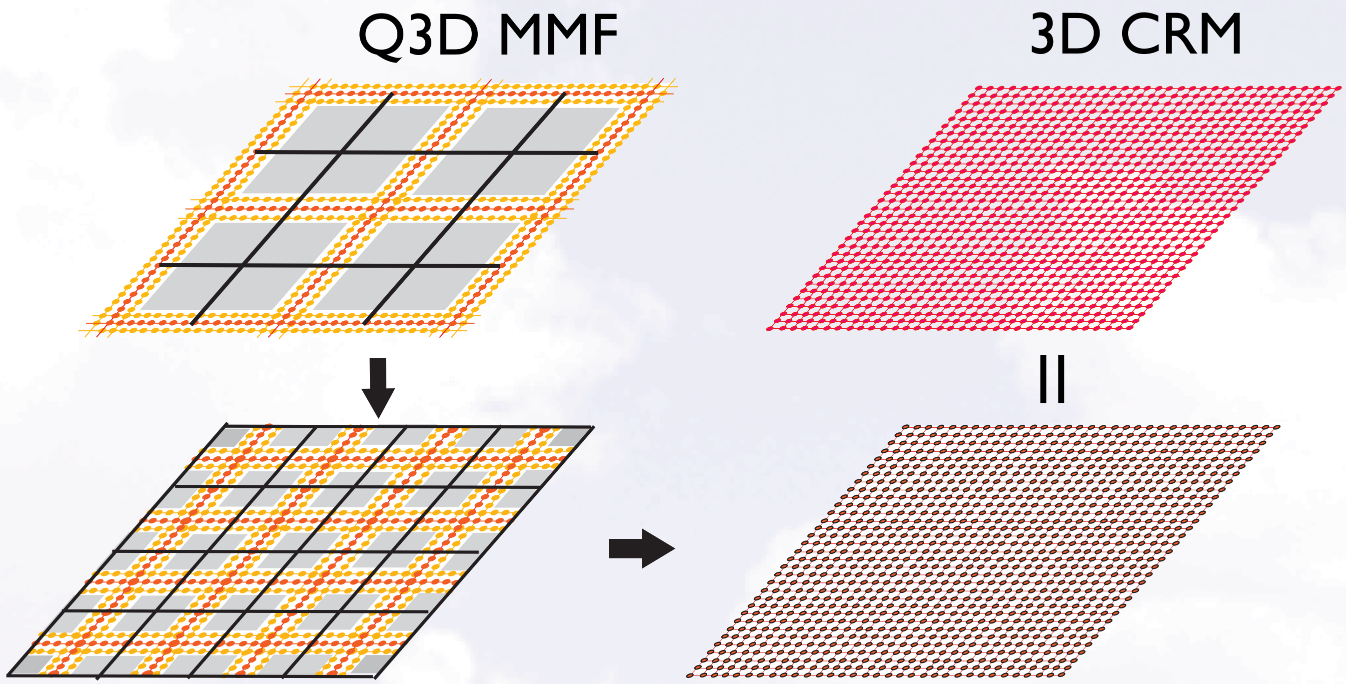
The quasi-3D multi-scale modeling framework (Q3D MMF) is an attempt to include 3D cloud effects in a GCM without necessarily using a fully three-dimensional global cloud-resolving model (GCRM).

The Q3D grid and lateral boundary condition



- The Q3D domain consists of two perpendicular sets of channels, each of which includes two or three 1D arrays of grid point.
- Perpendicular channels are coupled through averages along the channels and, therefore, they intersect only virtually.
- It is required that the values appearing in the lateral boundary condition have statistics similar to that of solutions.
- The easiest way of satisfying this requirement is to use a cyclic lateral boundary condition (CQ3D).

Convergence

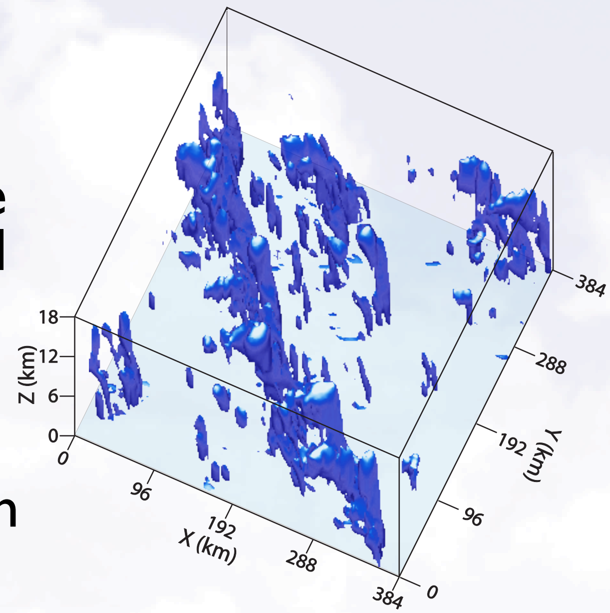


- Dynamics of the Q3D CRM by itself does not converge to a 3D CRM due to the use of the lateral boundary condition.
- The Q3D MMF, however, converges to a 3D CRM as the GCM grid size approaches to the CRM grid size.
- Thus the GCM grid size can be freely chosen depending on the objective of the application with essentially the same formulation of model physics.

In the Q3D MMF, the vector vorticity equation model (Jung and Arakawa, 2008) is applied to a combined system of 3D GCM and Q3D CRM.

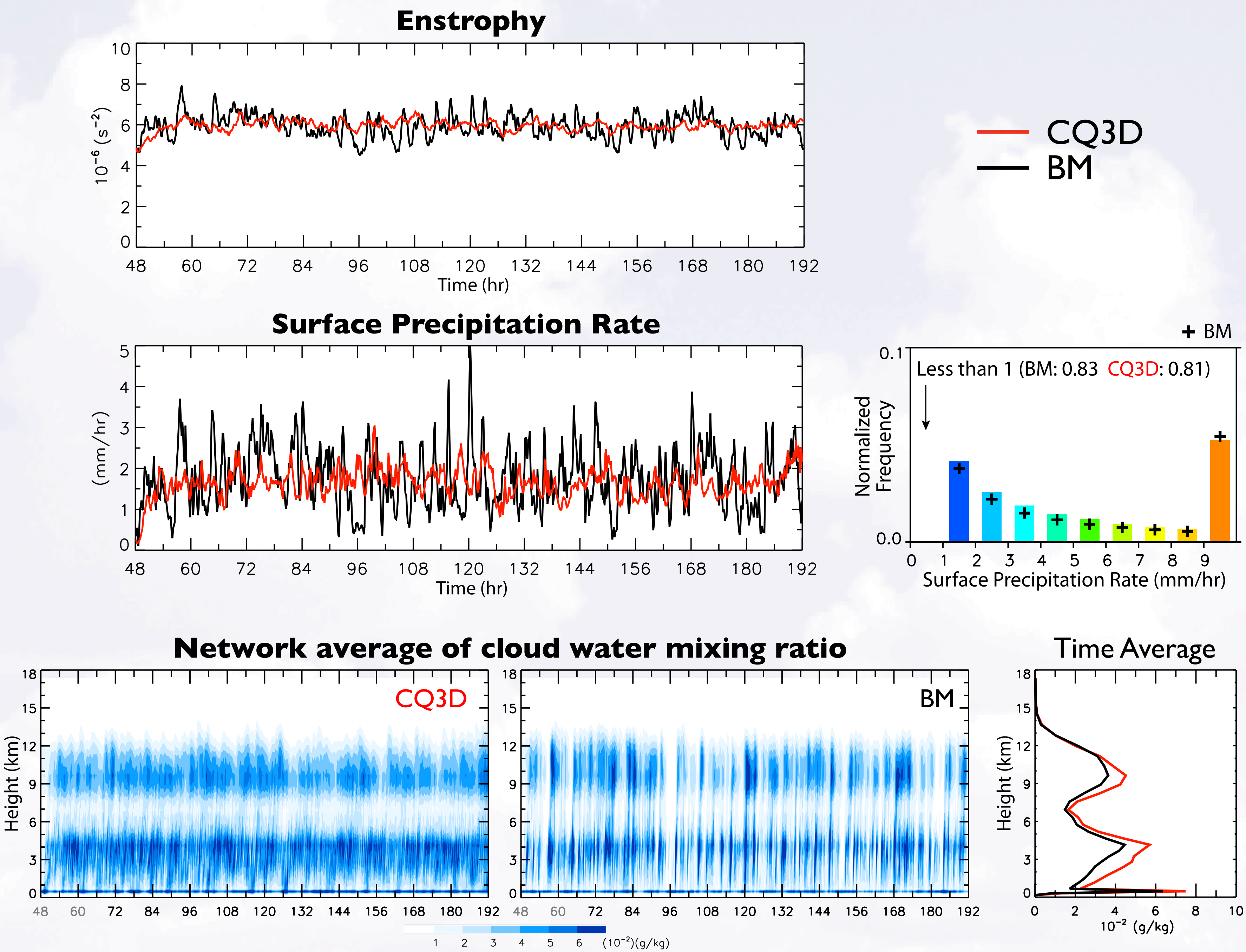
Preliminary tests

- **Benchmark simulation (BM):**
  A straightforward application of 3D CRM to simulate a development of an ensemble of clouds in a tropical condition (An example of cloud development is shown in the right).

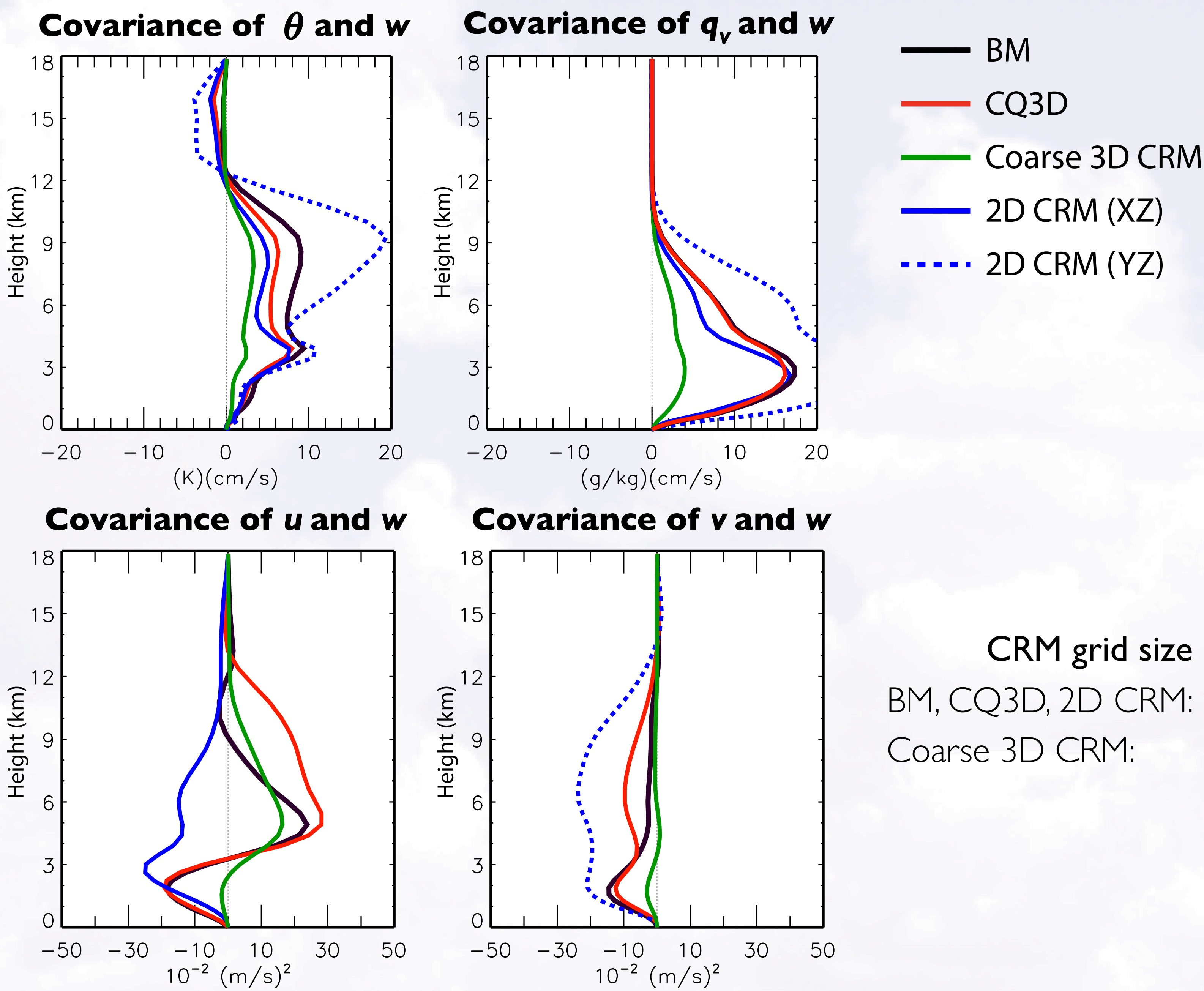


- Use an idealized small domain (384km x 384km).
- Prescribe vertical distributions of horizontally uniform cooling and moistening rates.
- The mean wind, potential temperature and water vapor are nudged to prescribed profiles.
- **Q3D MMF**: CRM grid size: 3km / GCM grid size: 384km
  - *We let the entire domain represent a single column of a GCM.*
  - *The ratio of the number of grid points of Q3D and 3D CRMs is 4.6%.*
- Compare the Q3D CRM and BM results side by side, including cloud-scale variances and covariances.

A highlight of results (I)



A highlight of results (II)



CRM grid size

BM, CQ3D, 2D CRM: 3km

Coarse 3D CRM: 17km

Summary and further comments

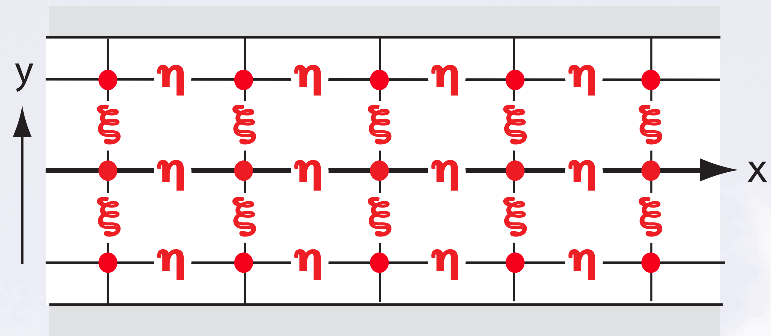
- Our effort in this research objective has been concentrated on the development of a Q3D algorithm based on a "gappy" grid.
- The formulation of lateral boundary condition is central to the development of the Q3D algorithm.
- The application of the cyclic Q3D (CQ3D) CRM to an idealized small domain is highly successful. It reproduces most of the important statistics of the benchmark 3D solutions.
- Comparisons with the results of a 2D CRM and a coarse-resolution 3D CRM indicate that an MMF based on the CQ3D CRM will be a useful framework for climate modeling.
- Various attempts to further improve the Q3D CRM were not successful, indicating that we have almost reached a plateau in the approach without using an interactive GCM.

Future plans

Short-term (by July 2011)

- Restructure the Q3D grid

  Within each channel, currently there are three grid-point arrays for η and scalar prognostic variables while there are only two grid-point arrays for ξ. To avoid the imbalance in the degrees of freedom between them at its origin, we will eliminate the third array. This will make the model more efficient roughly by the factor of 2/3.



ξ : x component of vorticity
η : y component of vorticity
• : scalar variables

- Fully document the Q3D algorithm and clean up the code.
- Parallelize the code and start working with a larger domain.
- Develop a Q3D MMF through coupling the Q3D CRM with an idealized GCM.
- Start implementing the Q3D CRM into the geodesic global model.

Long-term (after July 2011)

- Complete implementing the Q3D CRM into the geodesic global model.
- Evaluate the global Q3D MMF in view of climate simulation.