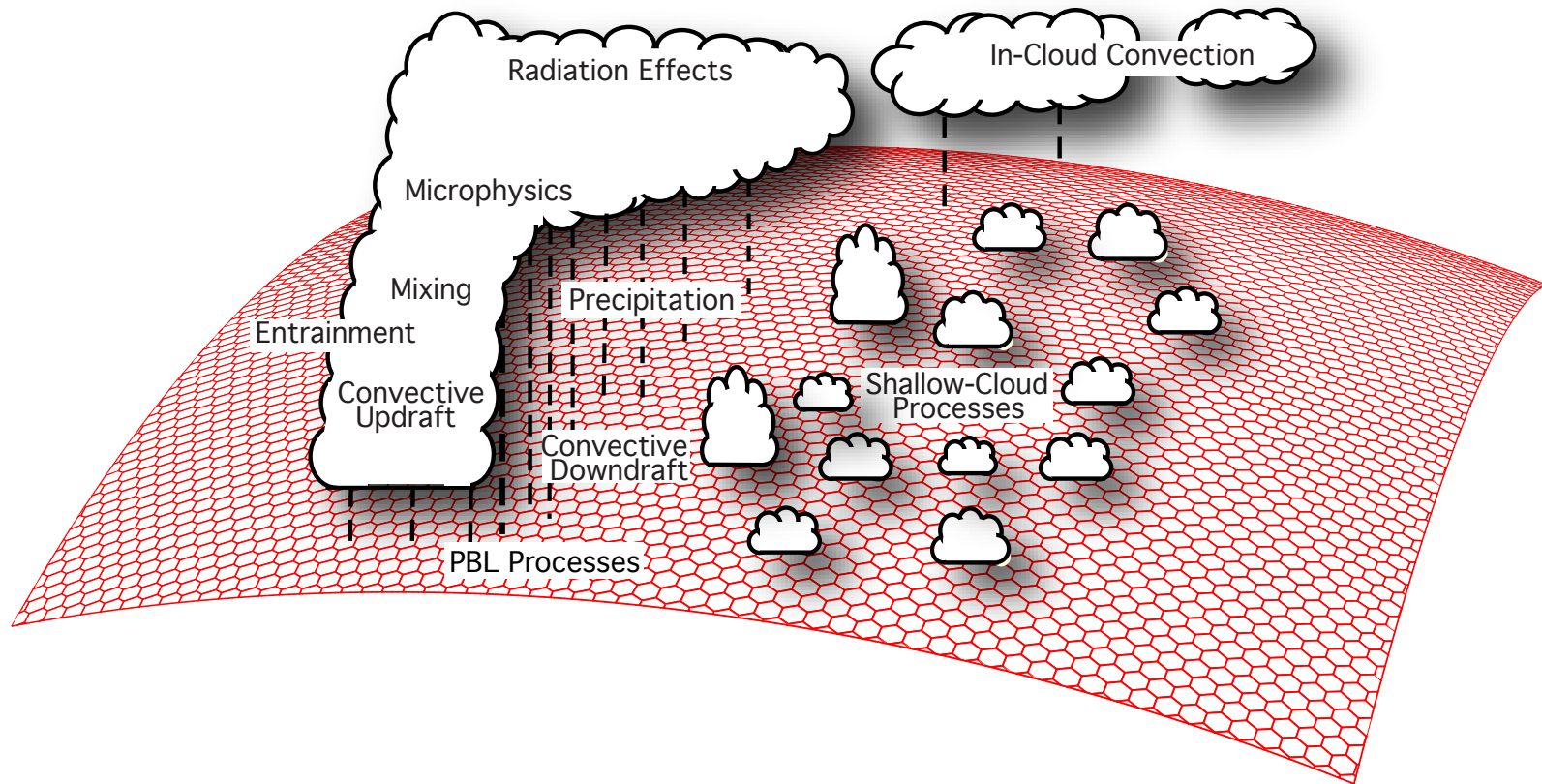# A Vector-Vorticity Global Cloud Resolving Model (VV-GCRM)

Celal Konor, Joon Hee Jung, Ross Heikes and David Randall
Colorado State University

Akio Arakawa
UCLA

- A "limited area" vector-vorticity cloud resolving model on a hexagonal grid

- The model applied to the spherical hexagon-pentagon geodesic grid

Major Atmospheric Processes Captured by A Cloud Resolving Model

Radiation Effects

In-Cloud Convection

Microphysics

Mixing

Precipitation

Entrainment

Convective Updraft

Shallow-Cloud Processes

Convective Downdraft

PBL Processes

Vector-Velocity Dynamical Core

- Based on anelastic (expandable to pseudo-compressible) equations.

- Predicts the 3D vorticity and maintains the non-convergence of the 3D vorticity.

- Sound wave filtering elliptic equation solves the vertical velocity. (Pseudo-compressible version solves a parabolic relaxation equation instead.)

- Having elliptic equation to determine the vertical velocity, instead of pressure as in the traditional anelastic models, simplifies the formulation of the lower boundary condition over ragged mountains.

- Post vorticity analysis is greatly simplified because the vorticity is directly predicted.

Grid Structure of the VV-GCRM

3-D view of the grid
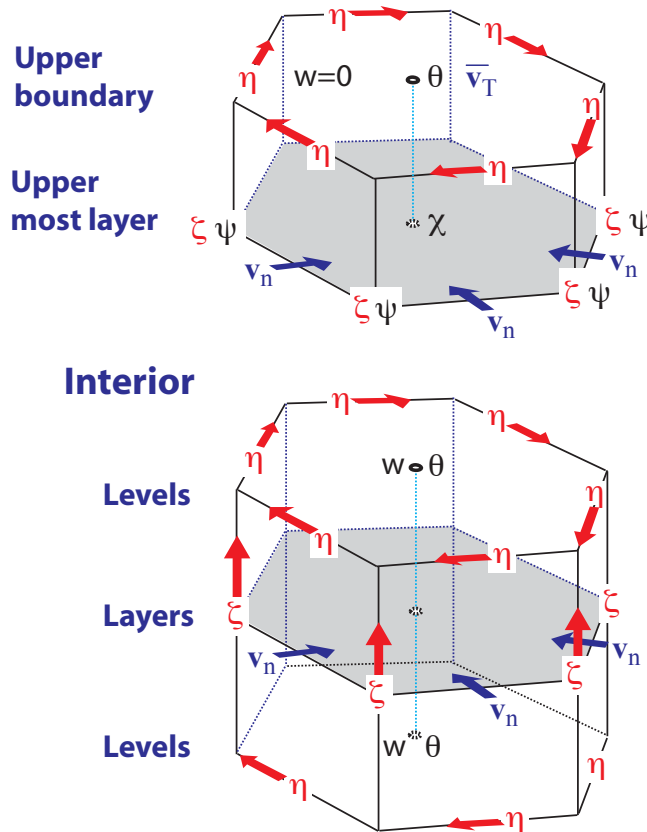
Charney-Phillips vertical grid

Advections of quantities defined at walls, corners and centers are needed.

A new indexing structure is introduced to simplify the expressions of finite-difference schemes on the hexagonal grid.

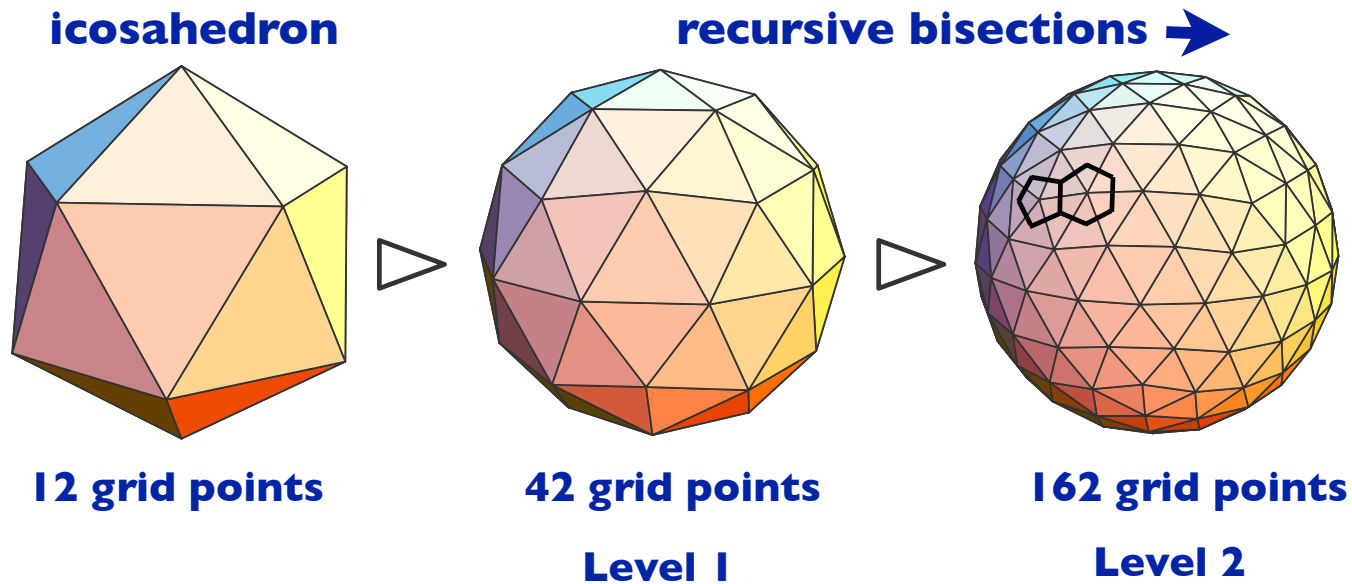# Domain of the Limited Area Version of Vector-Vorticity Cloud Resolving Model (VV-CRM)

$j \uparrow$

$i \rightarrow$
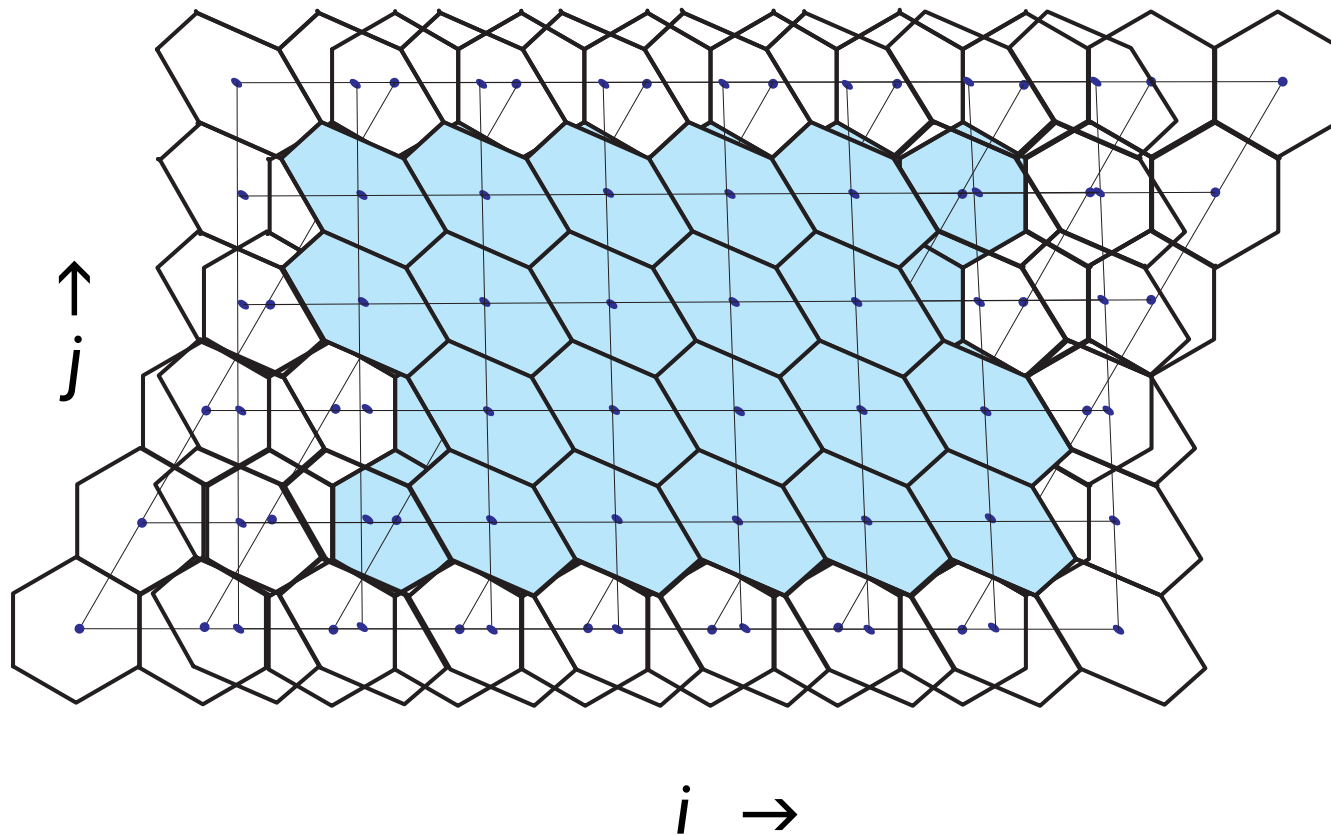
Blue is the quasi-square domain of the model.

Hexagon/Pentagon Geodesic Grid

Heikes and Randall (1995)

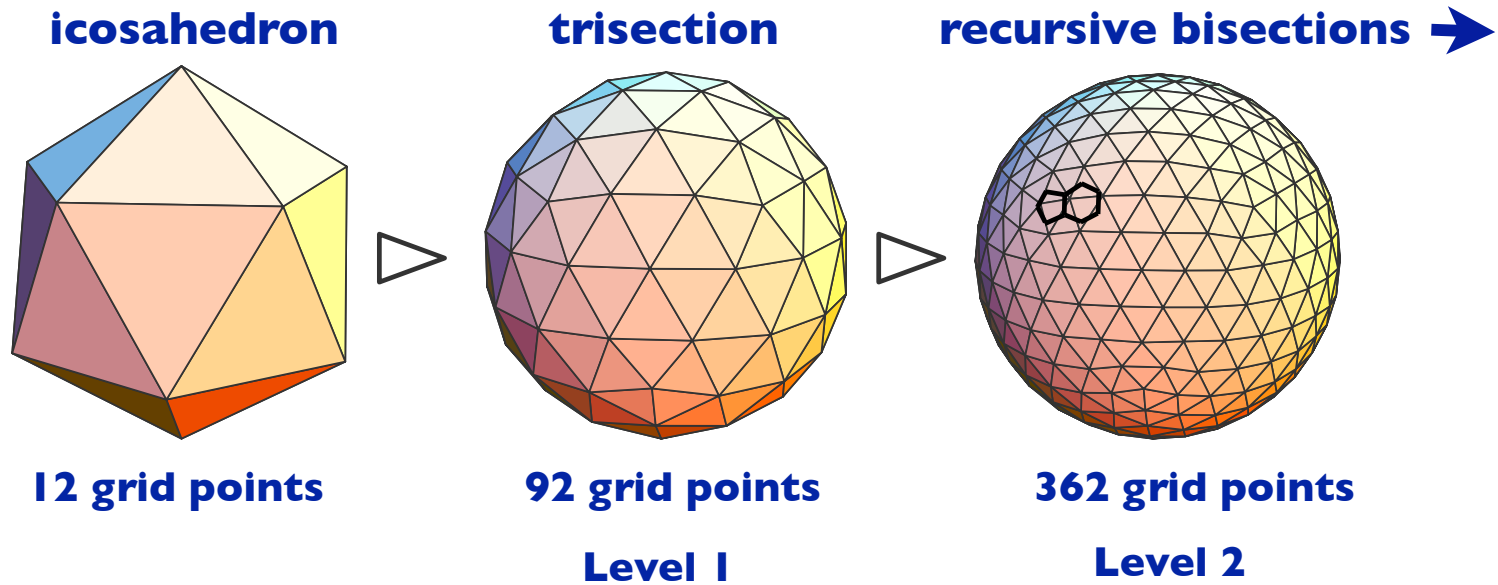*First Step: Recursively Bisecting an Icosahedron to Generate the Grid*

icosahedron

recursive bisections ➡

12 grid points

42 grid points

Level 1

162 grid points

Level 2

Number of cells

level of recursion	number of cells	distance between grid points (km)
9	2,621,442	15.64
10	10,485,762	7.819
11	41,943,042	3.909
12	167,772,162	1.955
13	671,088,642	0.977

- Number of grid points quadruples after every bisection.

Hexagon/Pentagon Geodesic Grid

Trisecting an Icosahedron followed by recursive bisections to generate the grid


icosahedron

trisection

recursive bisections ➡

12 grid points

92 grid points

Level 1

362 grid points

Level 2

Number of cells

level of recursion	number of cells	distance between grid points (km)
9	2,621,442	15.64
9*	5,898,242	
10	10,485,762	7.819
10*	23,592,962	
11	41,943,042	3.909
11*	94,371,842	
12	167,772,162	1.955
12*	377,487,362	
13	671,088,642	0.977

(*) Recursive bisections after an initial trisection.

Application from Limited area to Global Domain
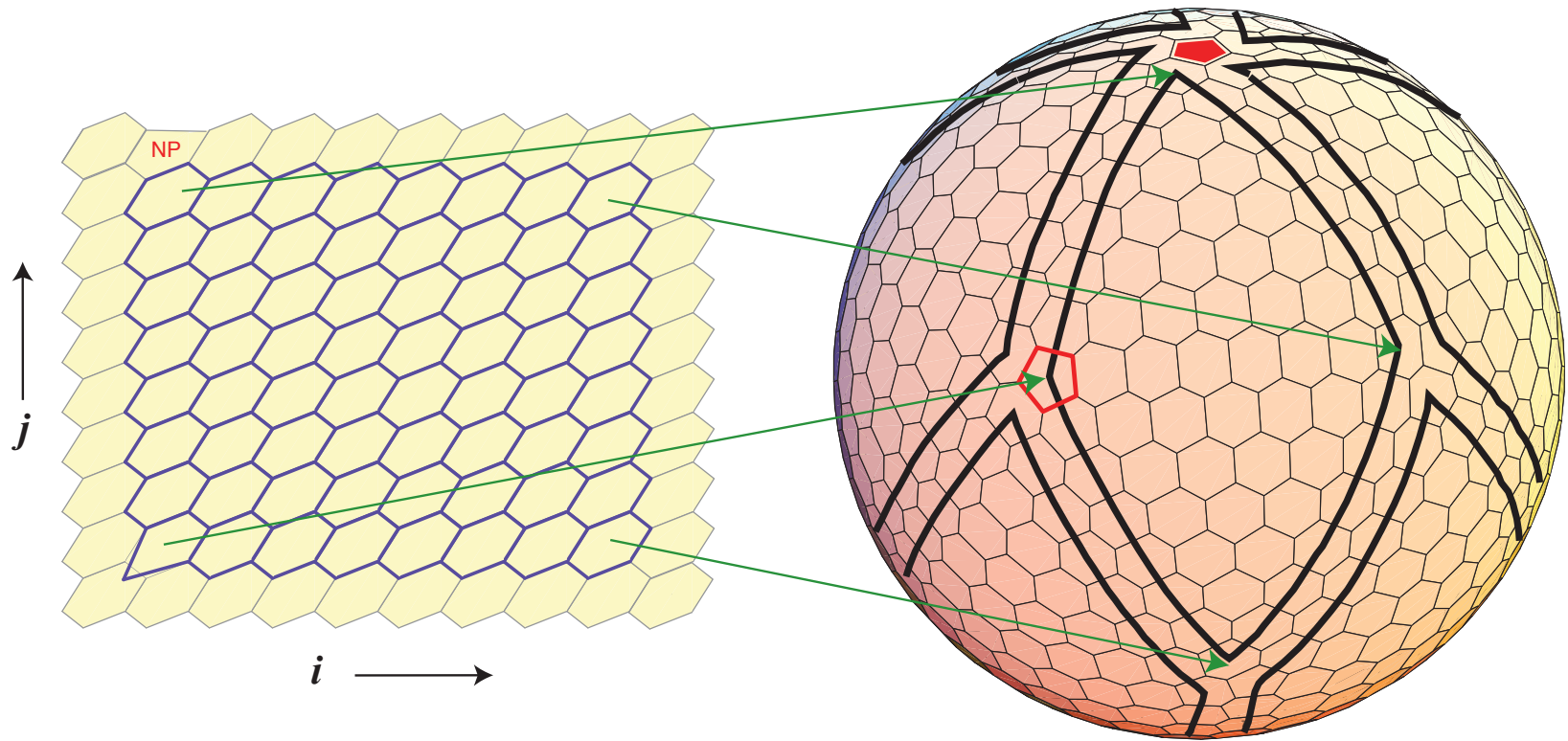
GCRM storage requirements for a restart file

❖ Assume the following prognostic fields:

- vertical component of vorticity at cell corners (×2)
- horizontal component of vorticity at cell edges (×3)
- potential temperature at cell centers (×1)
- 6 species of water at cell centers (×1)

❖ total bytes = (12 fields) × (4 time levels) × (8 bytes per word) × (number of cells) × (number of layers)

number of bytes (1e9)		number of cells (1e6)			
		10.5 (8 km)	41.9 (4 km)	167.8 (2 km)	671.1 (1 km)
number of layers	64	258	1031	4123	16493
	96	387	1546	6185	24739

⬡ We may need to store 10 of compatible size file during an integration with early versions.

GCRM memory requirements per process

❖ Assume the following 3D fields (prognostic and diagnostic):
- 12 prognostic variables (✕4 for Adams-Bashforth 3rd-order)
- vertical velocity at cell centers
- normal velocity at cell edges (✕3)
- radiation fluxes at cell centers
- 12 other fluxes and other stuff

❖ 65 total 3D (96 layer) fields

number of bytes (1e9)		number of cells (1e6)			
		10.5 (8 km)	41.9 (4 km)	167.8 (2 km)	671.1 (1 km)
number of processes	1	523	2094	8375	33500
	1024	0.51	2.04	8.18	32.7
	2048	0.26	1.02	4.09	16.4
	4096	0.13	0.51	2.04	8.18
	8192	0.06	0.26	1.02	4.09

Red numbers denote less then 4G of memory per process.

Model Verification Through Instrument Simulation Schemes
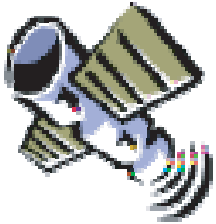
Run-time satellite data simulation to be compared to satellite observations

Run-time ground-based radar data simulation to be compared to radar observations

Run-time aircraft data simulation to be compared to in situ observations

Data Access and Visualization

- High performance data archiving and analyses system

- Parallel NetCDF for data format

- A data portal for easy access

- Usual visualization tools, such as cross-sections, movies, time-series

- A zoom feature at works
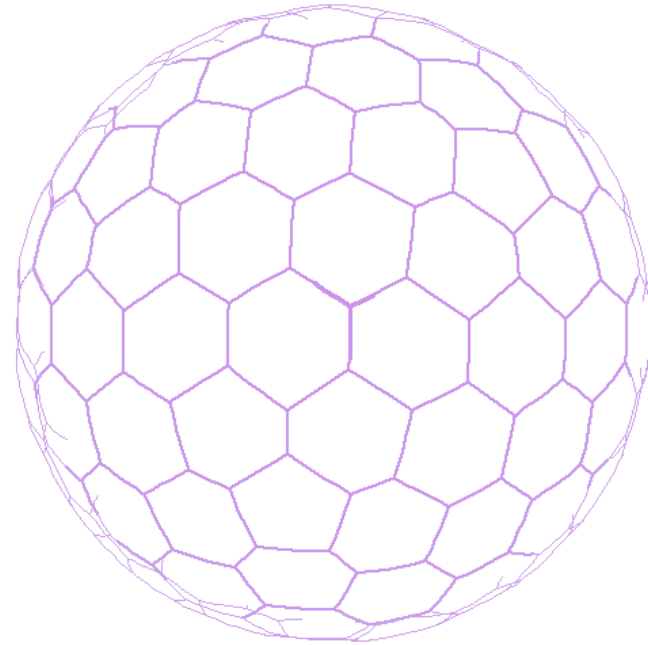
What is completed (limited area version)?

- Horizontal indexing scheme

- Selection of the domain and implementation of the boundary condition

- Three horizontal advection schemes of quantities defined at corners, walls and centers

What is left?

- *Horizontal elliptic solvers* for streamfunction (corners) and velocity potential (centers) at the upper boundary

- *3D elliptic solver* for vertical velocity (centers)

- Vorticity conversion terms and vertical advections
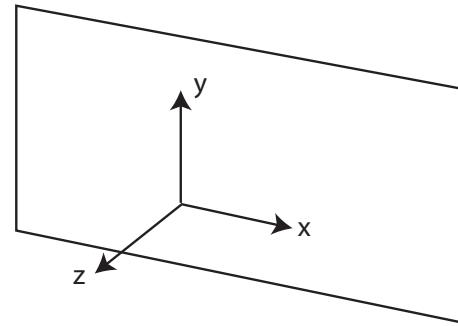
- Thermodynamic equation

- *Work starts for the global model in May and first results are due Aug 08.*

See next since we will spend some time to construct and test the equations of the global model (generalized anelastic equations)

Proposals for Continuation of the Limited Area VV-CRM Work

1-High resolution limited area model

To simulate cloud ensembles...

2-High resolution "Belt" model

To simulate MJO's, Hurricanes on an Equatorial beta-plane and extratropical cyclones on a mid-latitude beta-plane...