

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

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*National Center for Atmospheric Research, Boulder, Colorado, USA*

*This research has been supported by NSF AGS-1500187  
(and partly by DOE ACME DE-SC0016273 and DOE CMDV DE-SC0016305).*

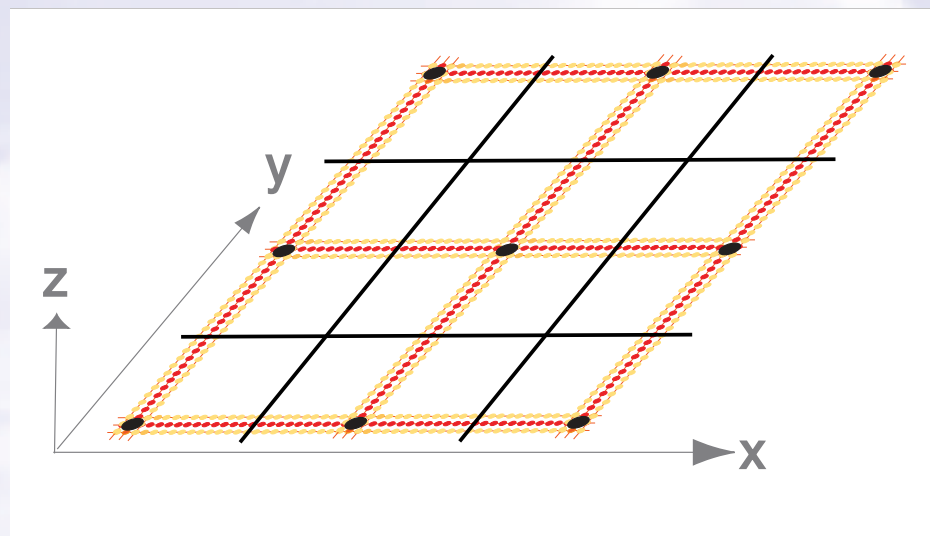
CESM: Atmosphere Model Working Group Meeting  
NCAR, Mesa Lab, Boulder, CO, February 19-21, 2019

# Quasi-3D Multiscale Modeling Framework

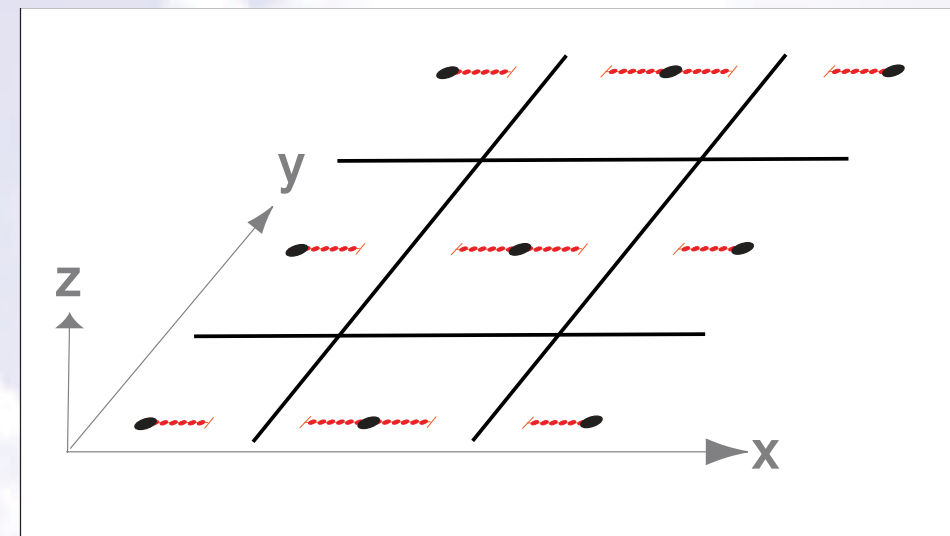
*Jung and Arakawa (2010, 2014), Jung (2016)*

- 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



## MMF



# GCM grid cell    ● GCM grid    ● CRM grid    ● CRM ghost grid

# Quasi-3D Multiscale Modeling Framework

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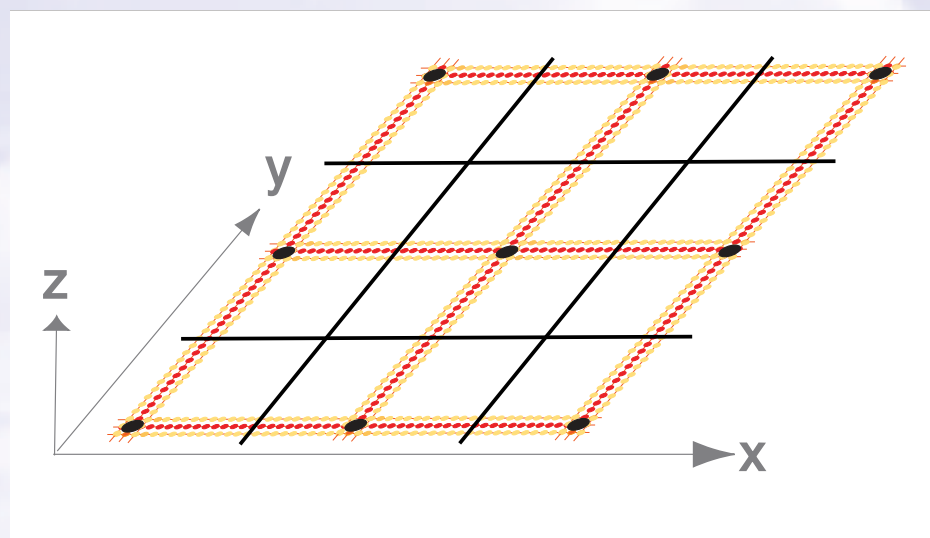
- CRMs in GCM grid columns are seamlessly connected;
- Two segments of CRMs perpendicularly pass each other (but don't intersect) at the center of each GCM cell;
- CRMs are three-dimensional, although covering only channel-like domains.

*Cloud systems travel freely along the CRM channels;*

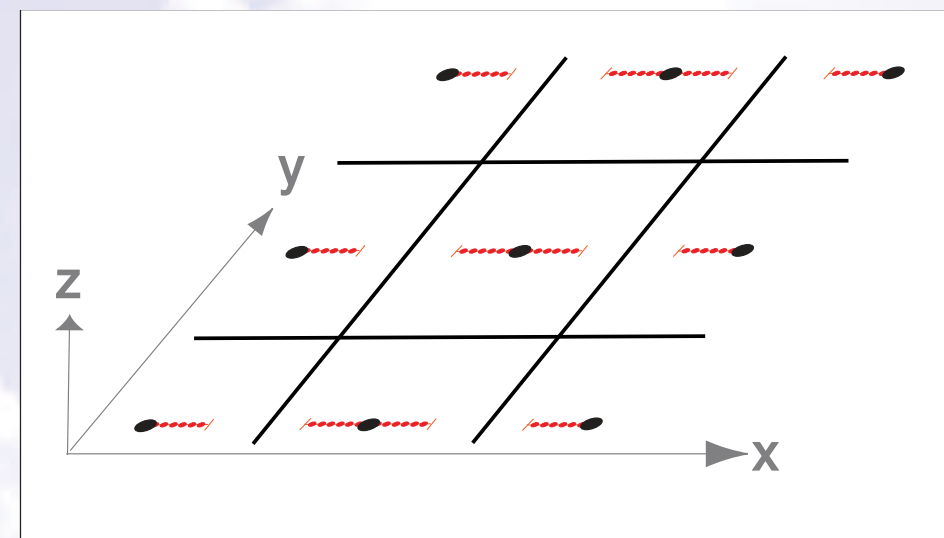
*Surface orography can be resolved by the CRMs;*

*Subgrid-scale vertical momentum transport can be directly simulated.*

## Q3D MMF



## MMF



# GCM grid cell    ● GCM grid    ● CRM grid    ● CRM ghost grid



# Development of a Global Q3D MMF

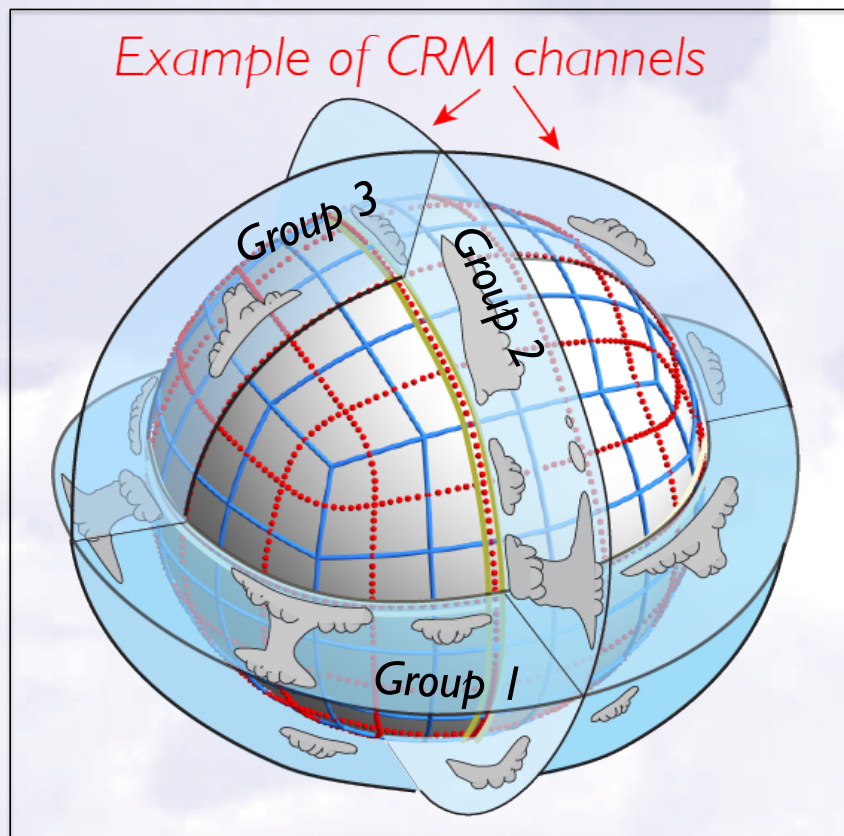
*A global version of Q3D MMF has been created.*

- **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*

# Development of a Global 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.



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- CRM-type physics parameterizations are included.

## ***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**

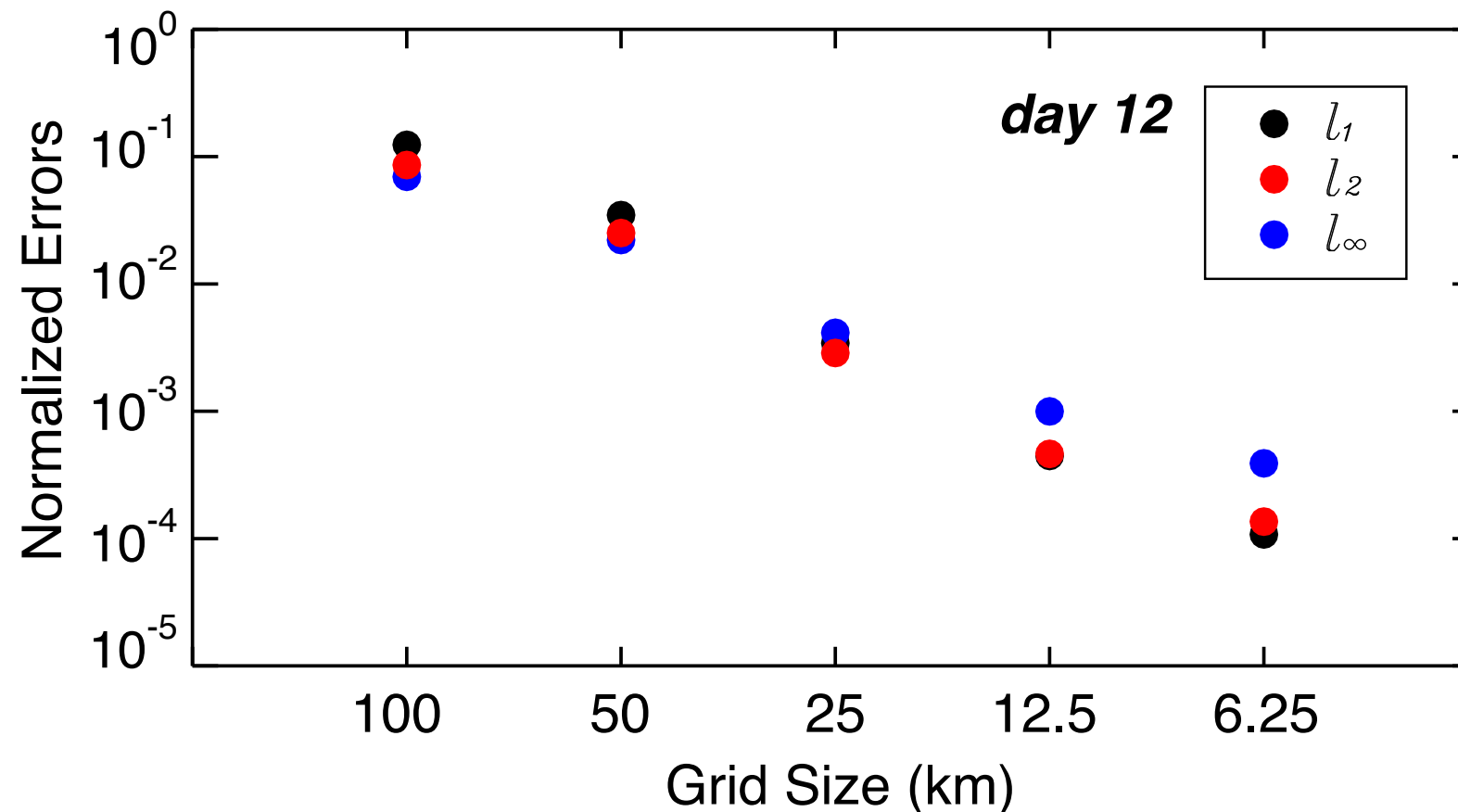
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*J. Adv. Model. Earth Syst. (in press)*



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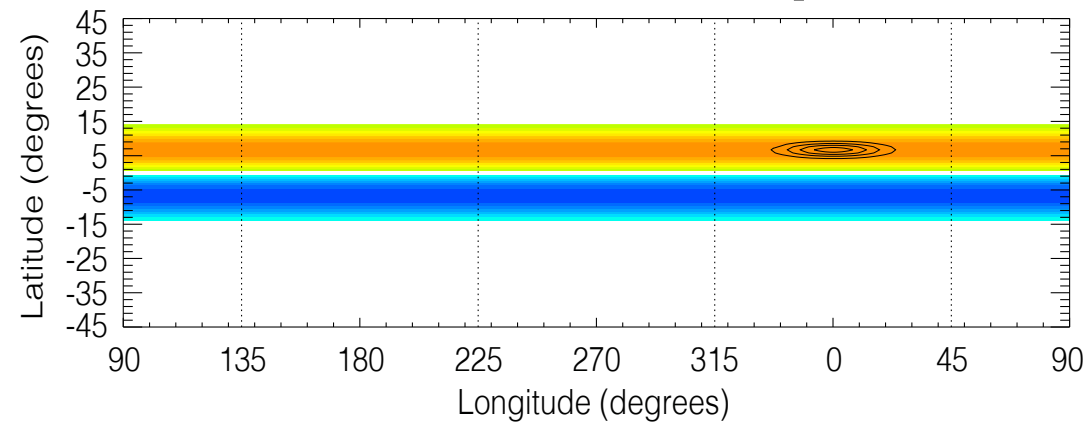
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**Rotation of a cosine bell along the equator**  
*Following Williamson et al. (1992)*



# VVM: Barotropic Instability Test (Case I)

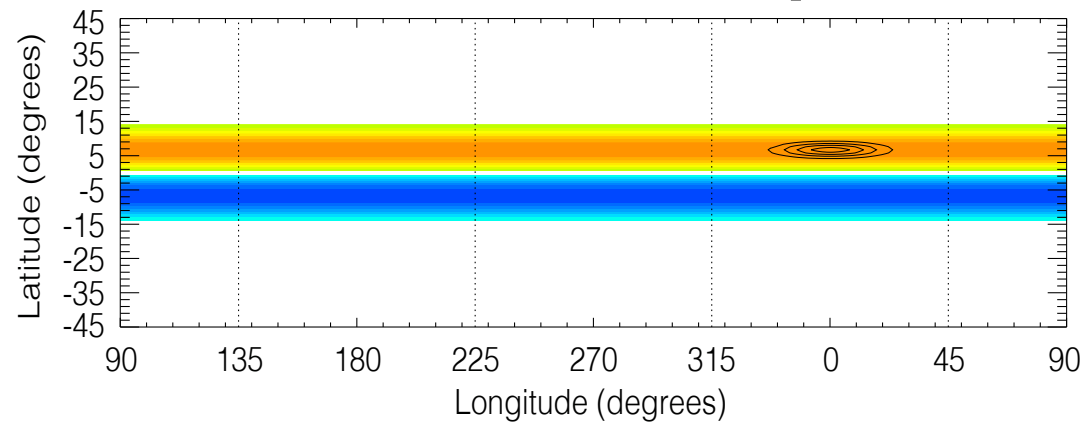
## *Initial Vorticity*



*Similar to  
Galewsky et al. (2004)*

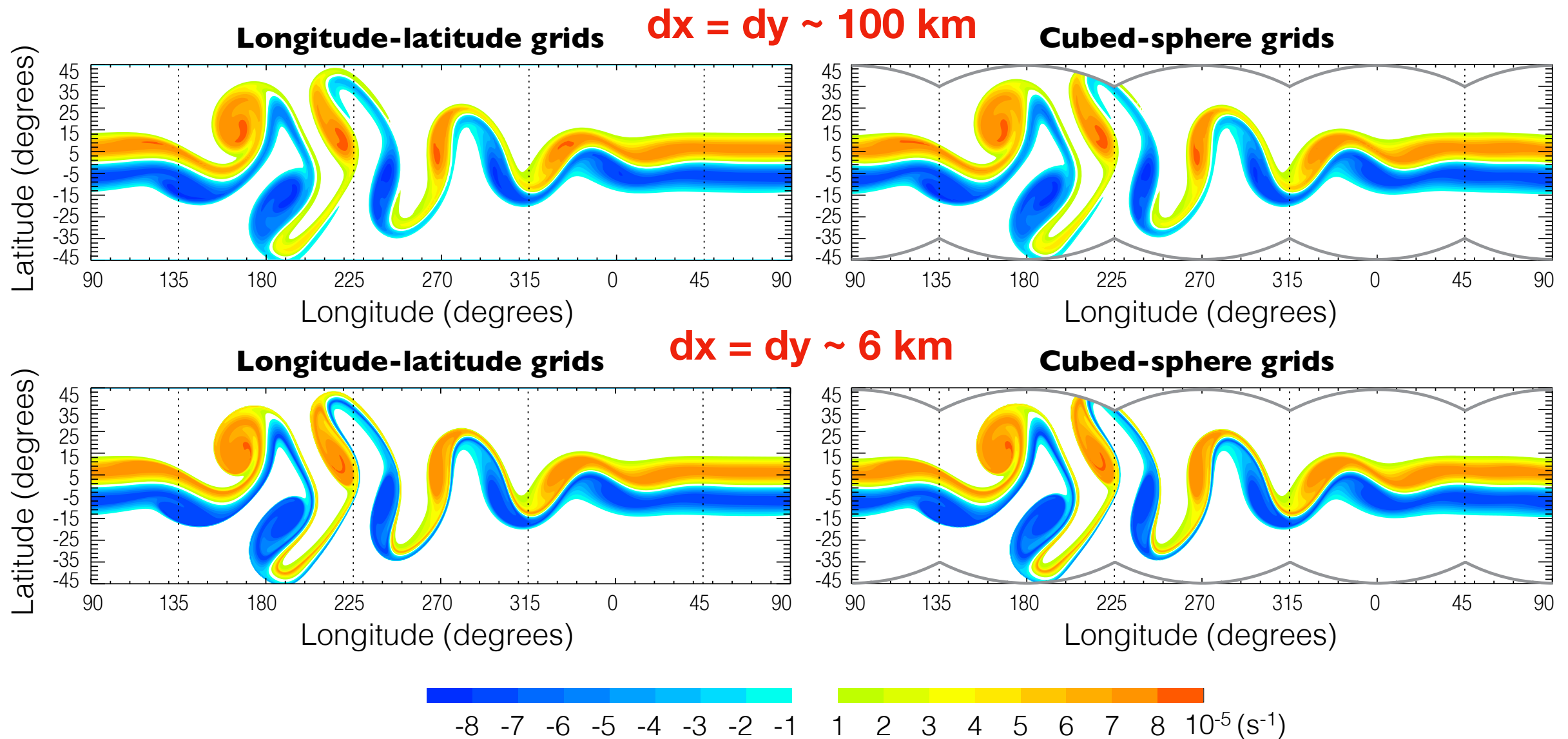
# VVM: Barotropic Instability Test (Case I)

## Initial Vorticity



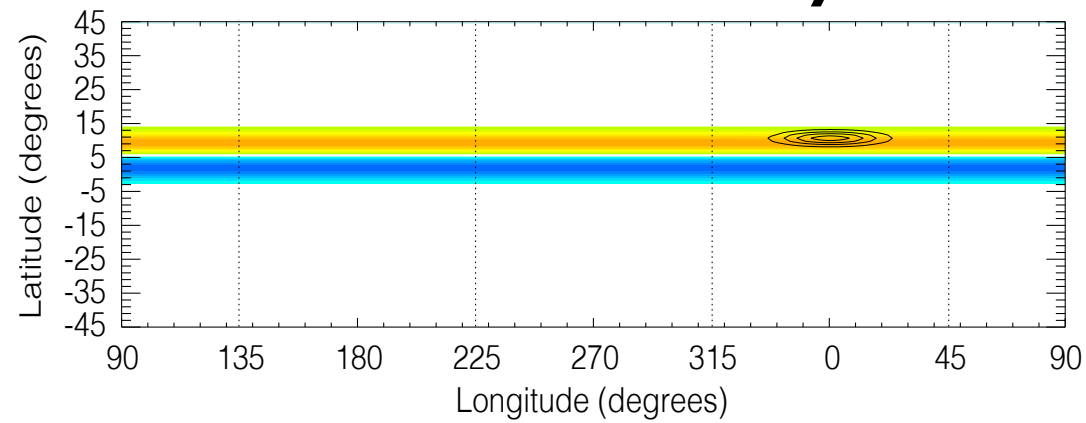
*Similar to  
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**$t = 168 h$**

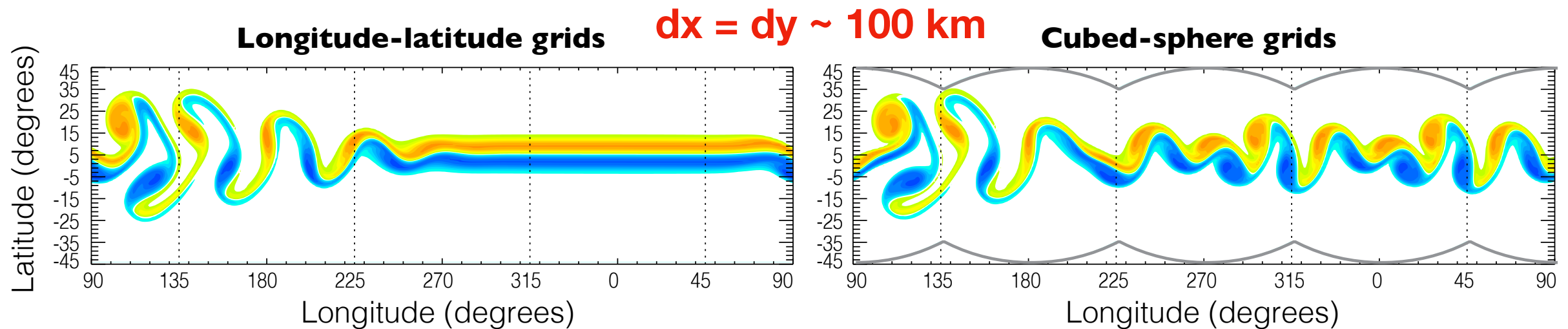


# VVM: Barotropic Instability Test (Case 2)

## Initial Vorticity



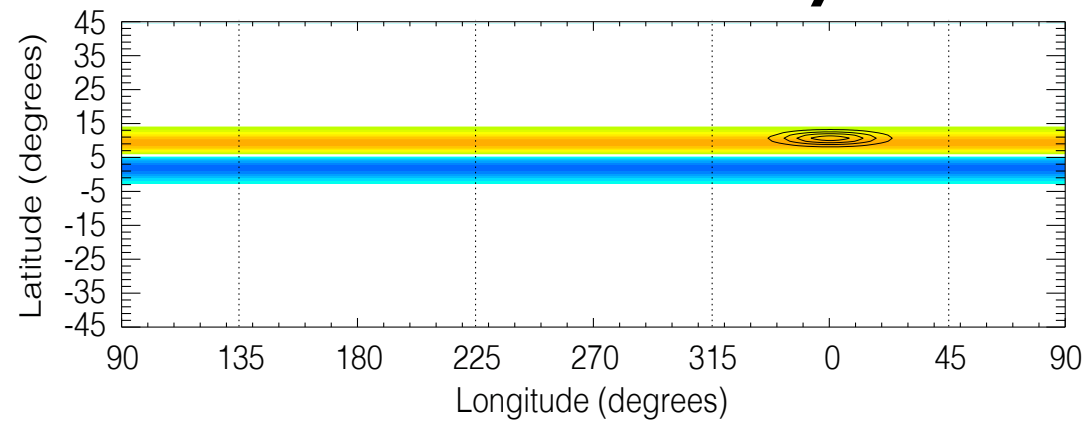
**$t = 120 h$**



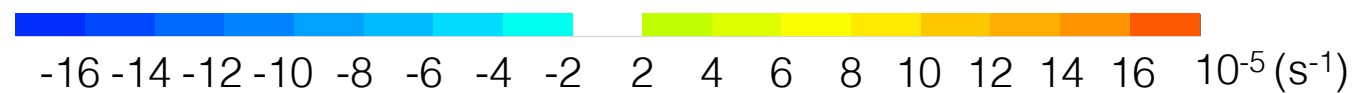
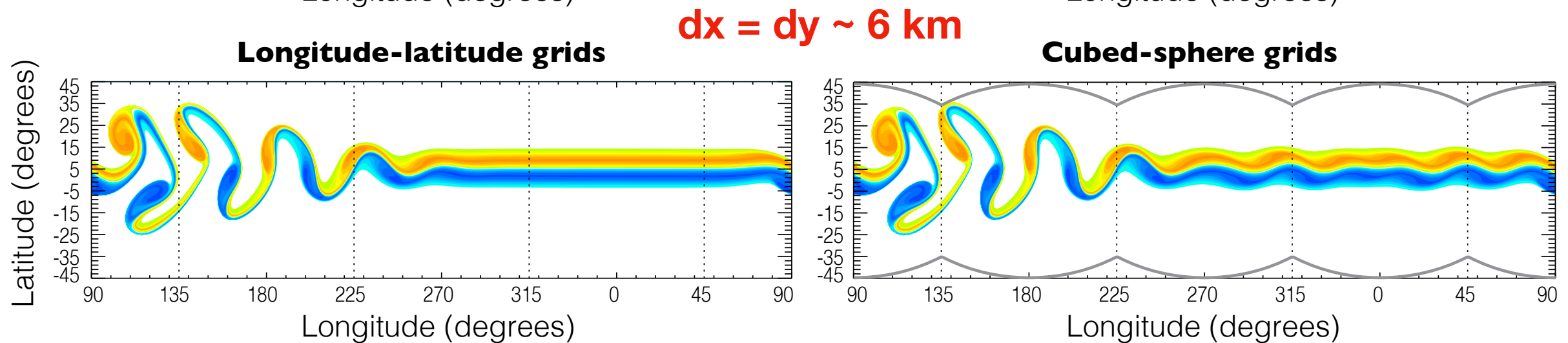
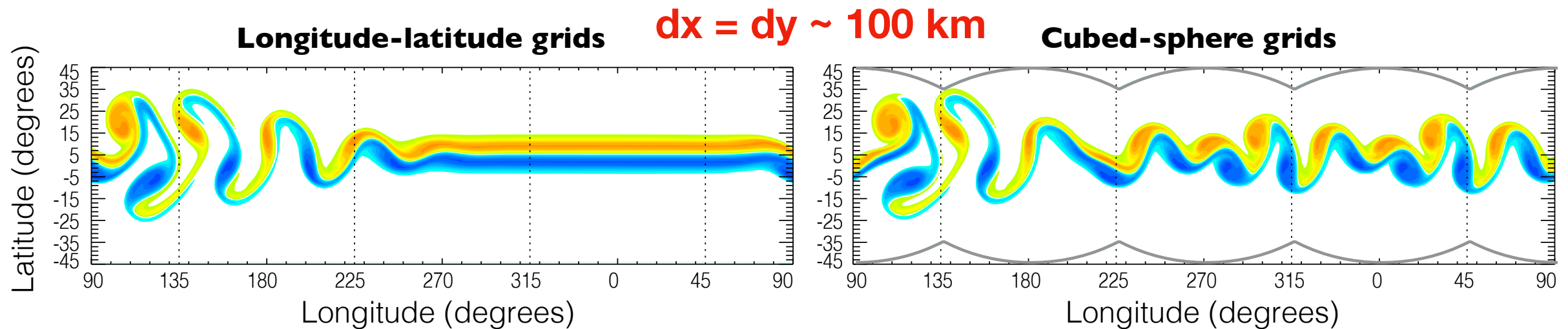


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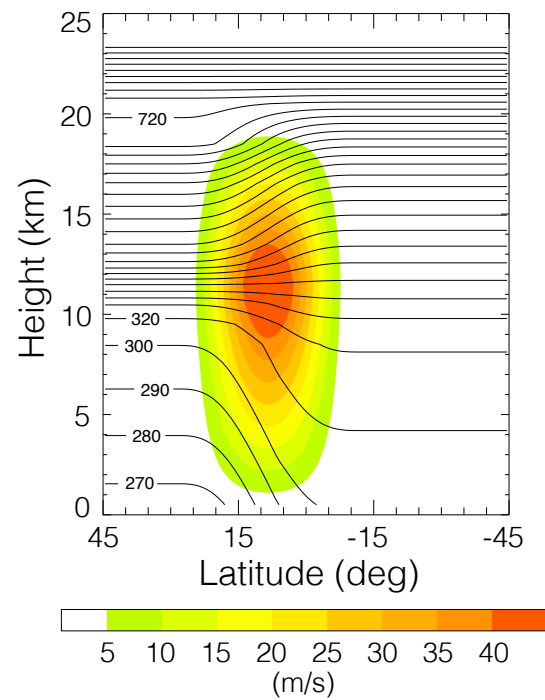
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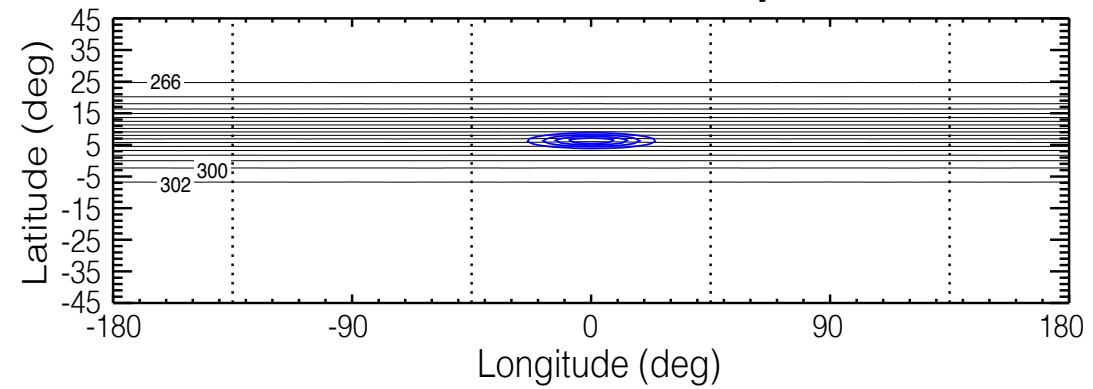
# VVM: Baroclinic Instability Test

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

**Zonally Uniform Initial State**



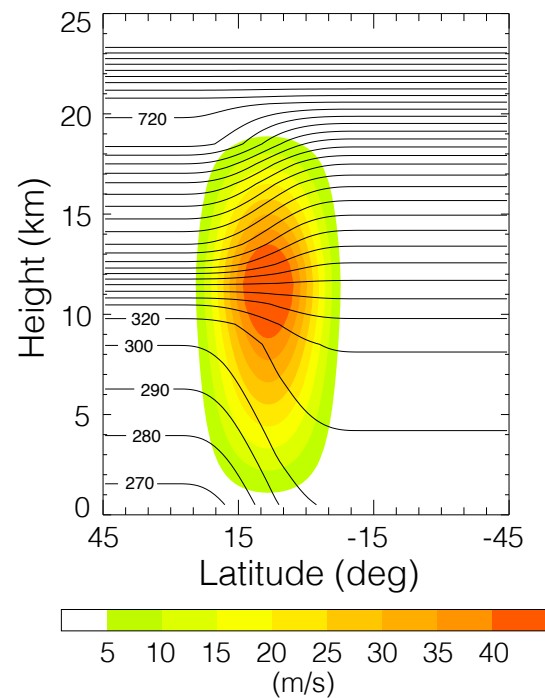
**Initial Perturbation on Potential Temperature**



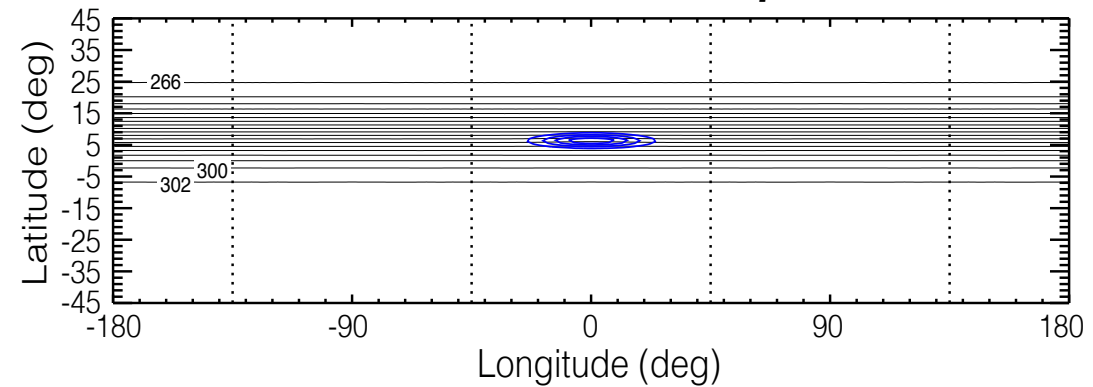
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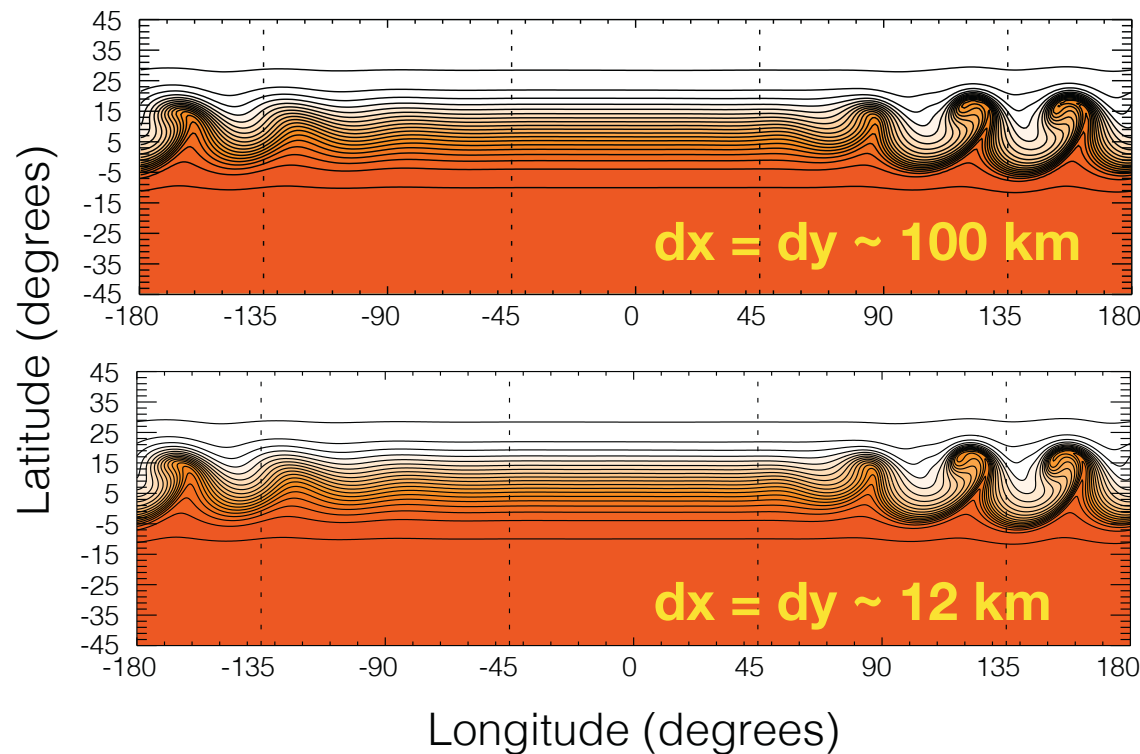


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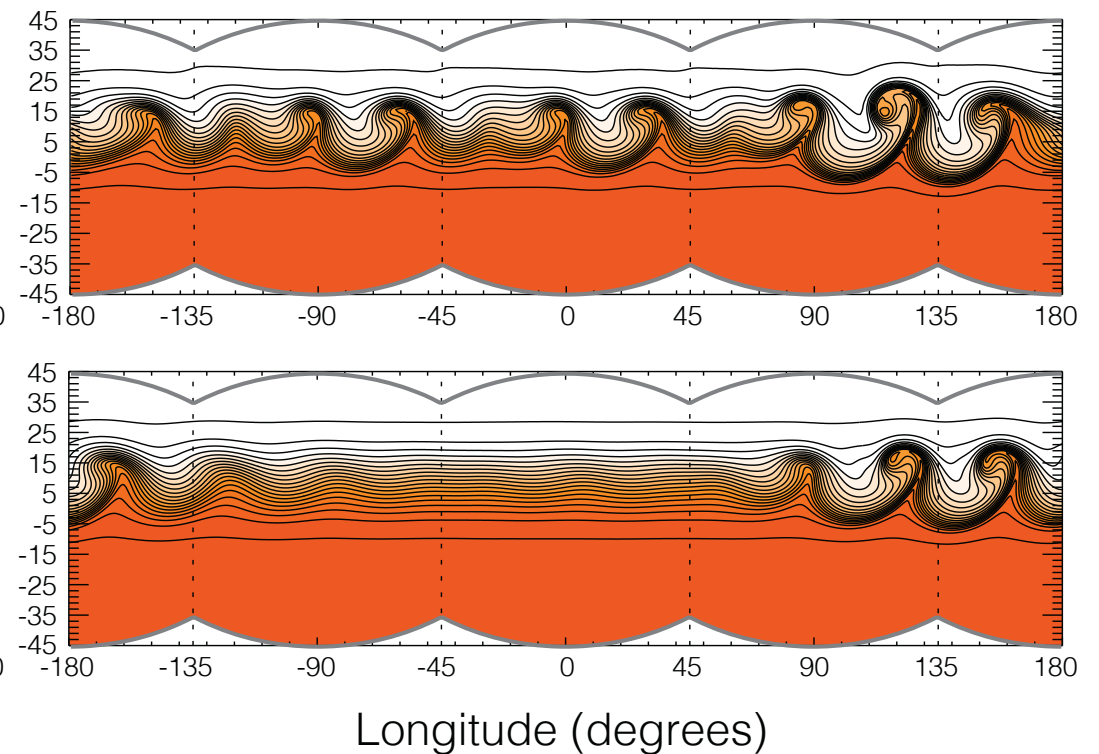


**$t = 288 h$**

**Longitude-latitude grids**



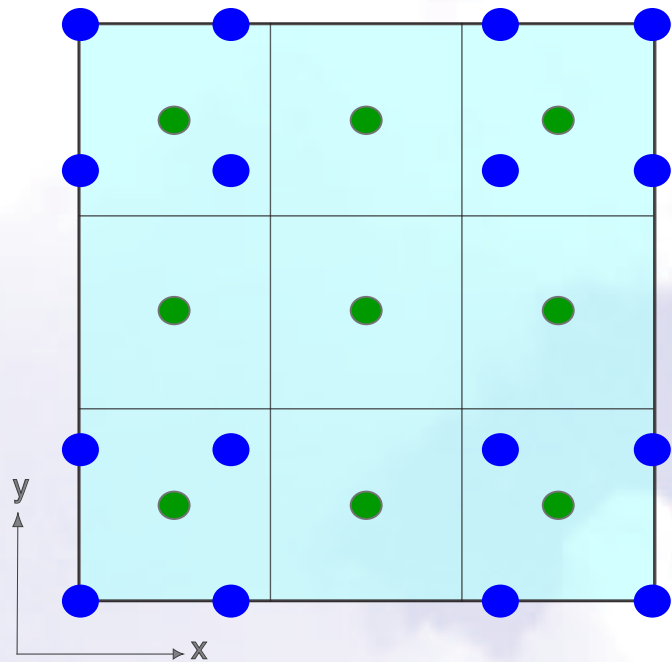
**Cubed-sphere grids**



# Horizontal Grid Structure of the Q3D MMF

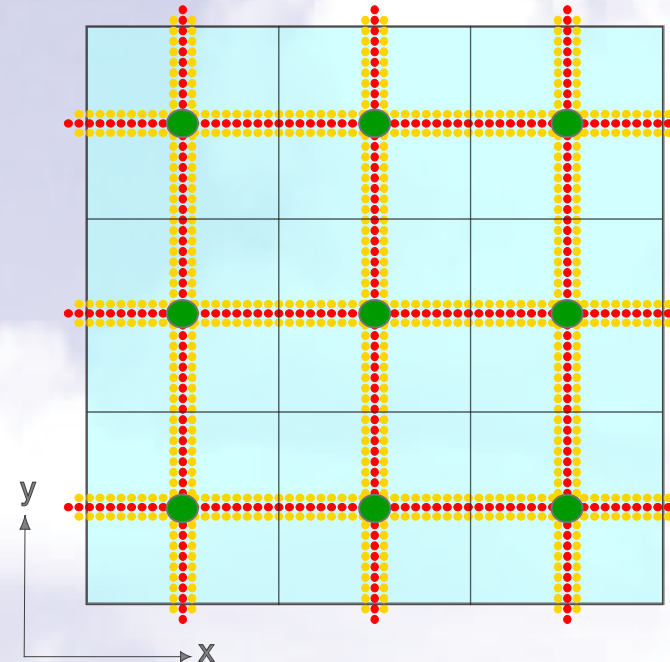
## Two Grid Systems

**Low-resolution GCM grid**



**GLL grid & physics grid (CSLAM configuration)**

**High-resolution CRM grid**



*The CRMs are coupled with the physics grids.*

*For communication, horizontal interpolation and cell-average are needed.*

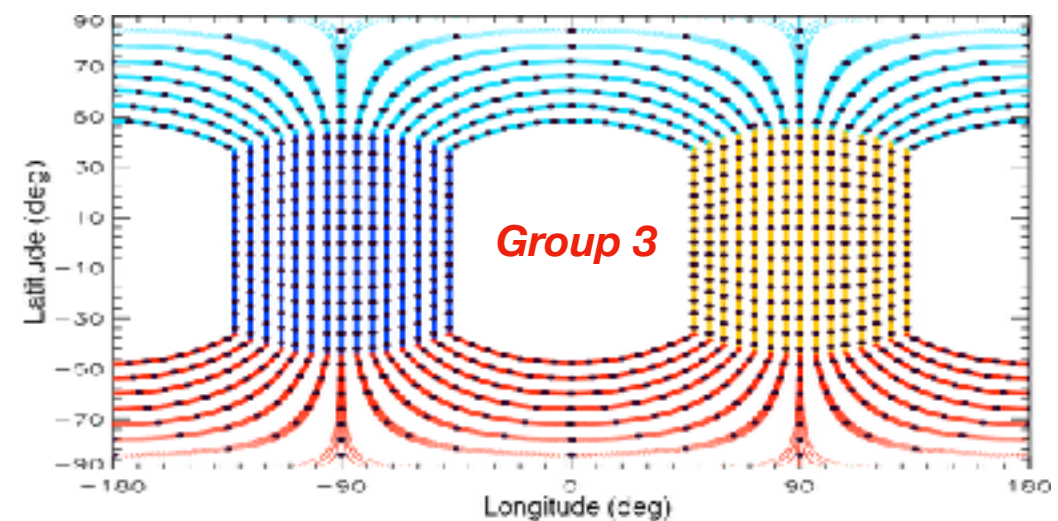
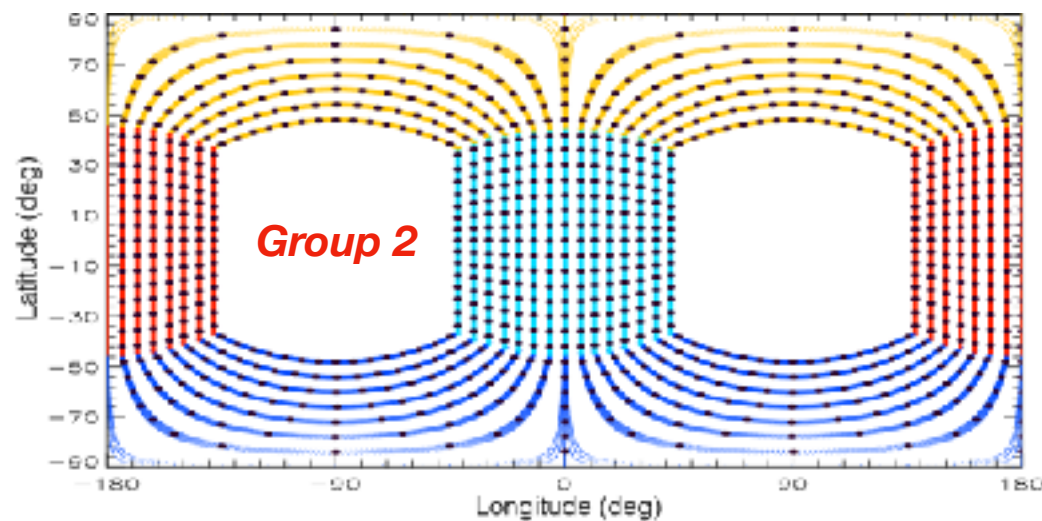
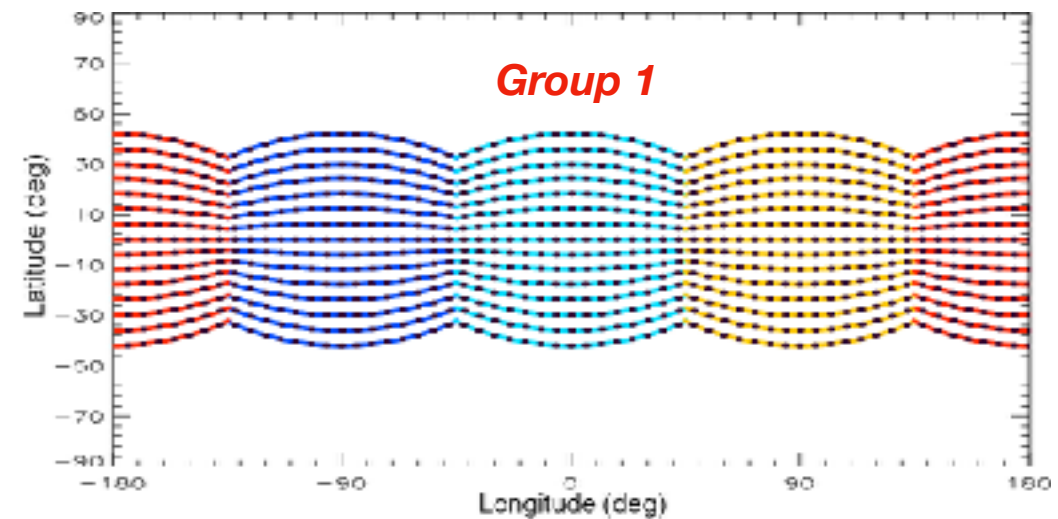
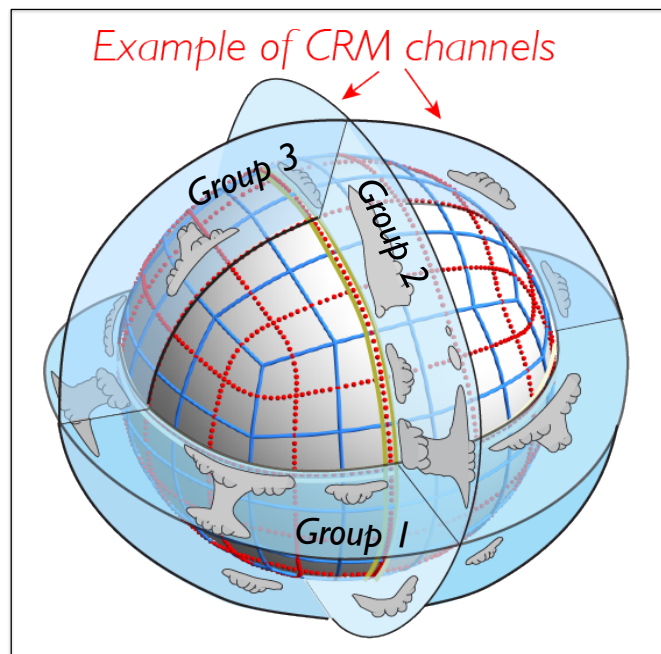


# Example of Horizontal Grid Distribution

$$N_{phy} = 3, N_e = 5, N_c = 25$$

$$(dx_{GCM} \sim 660 \text{ km}, dx_{CRM} \sim 26 \text{ km})$$

## CRM grid channels



# of physics-grid columns on the sphere =  $(N_{phy} \times N_e)^2 \times 6 = 1,350$

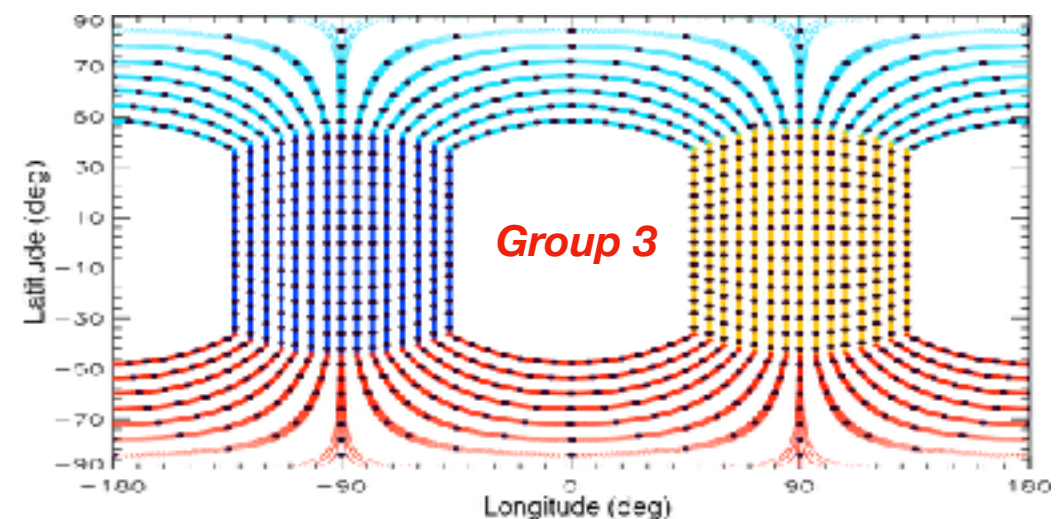
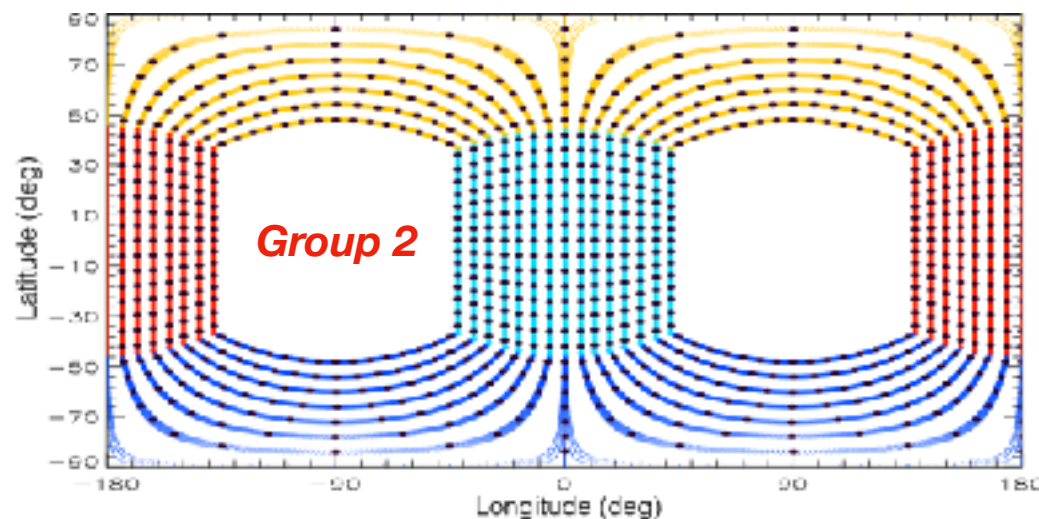
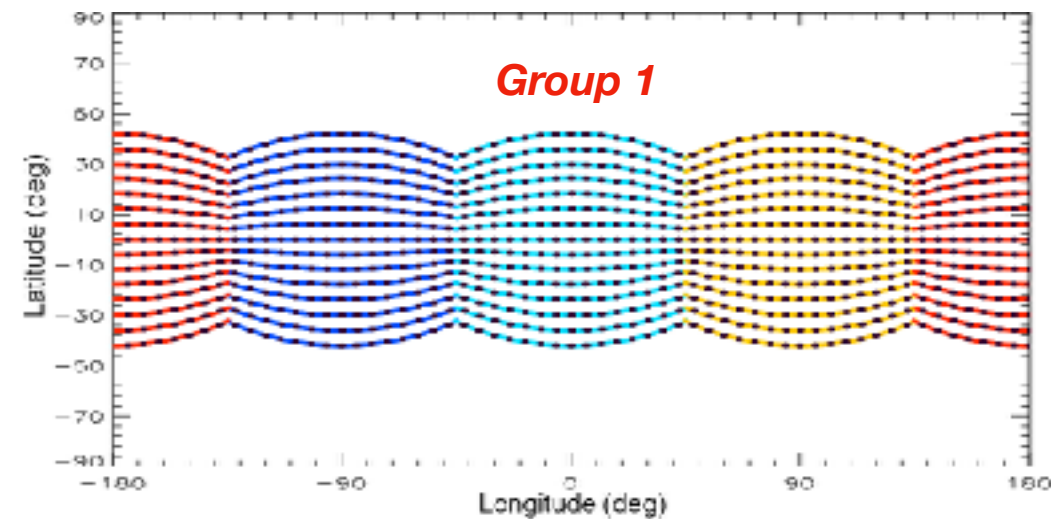
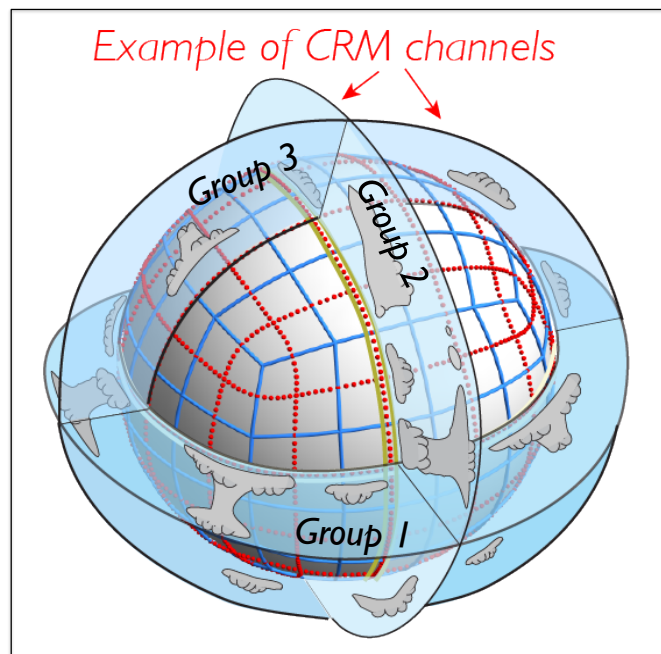
# of CRM-grid columns on the sphere = (# of physics-grid columns)  $\times N_c \times 2 = 67,500$

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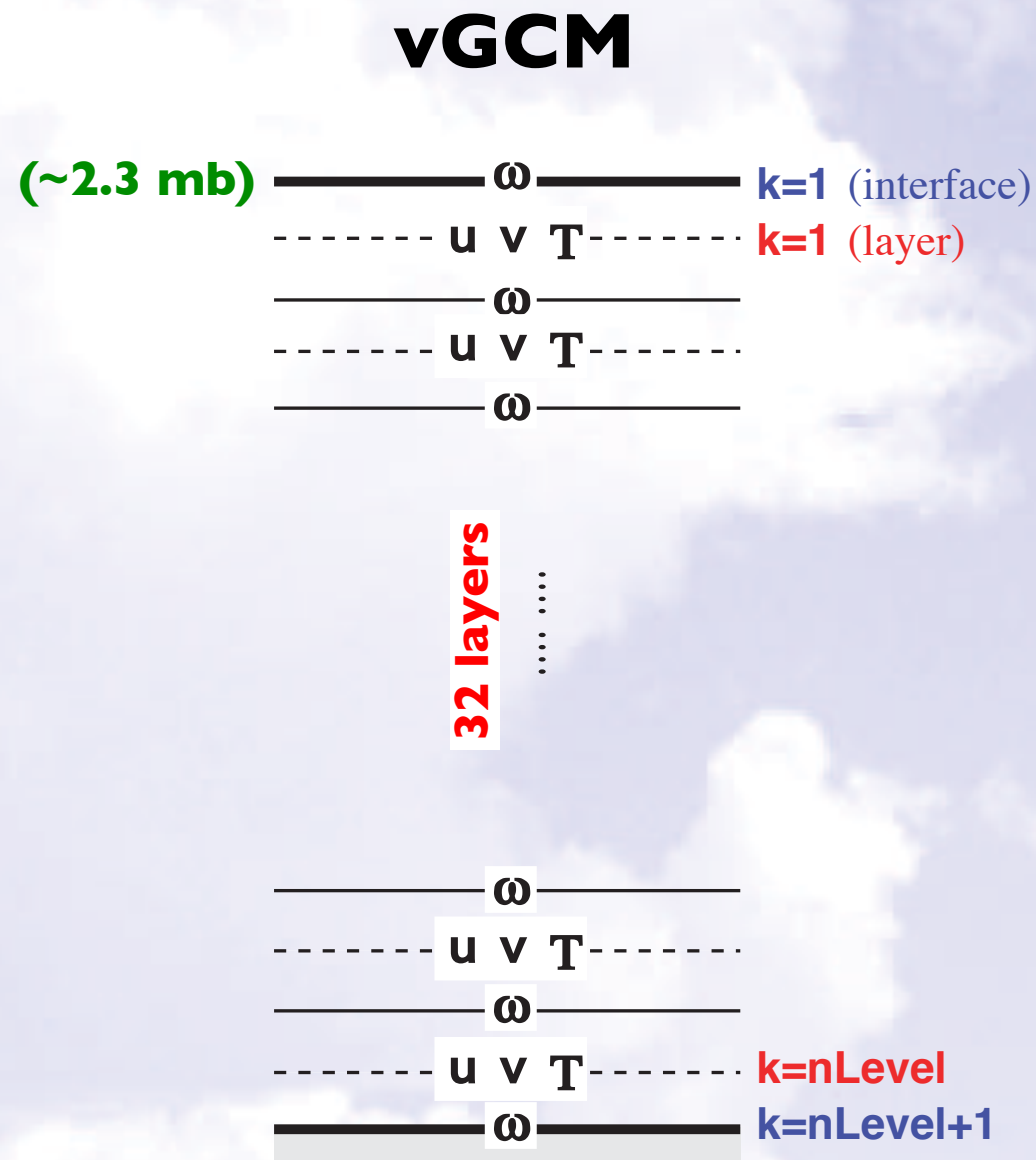
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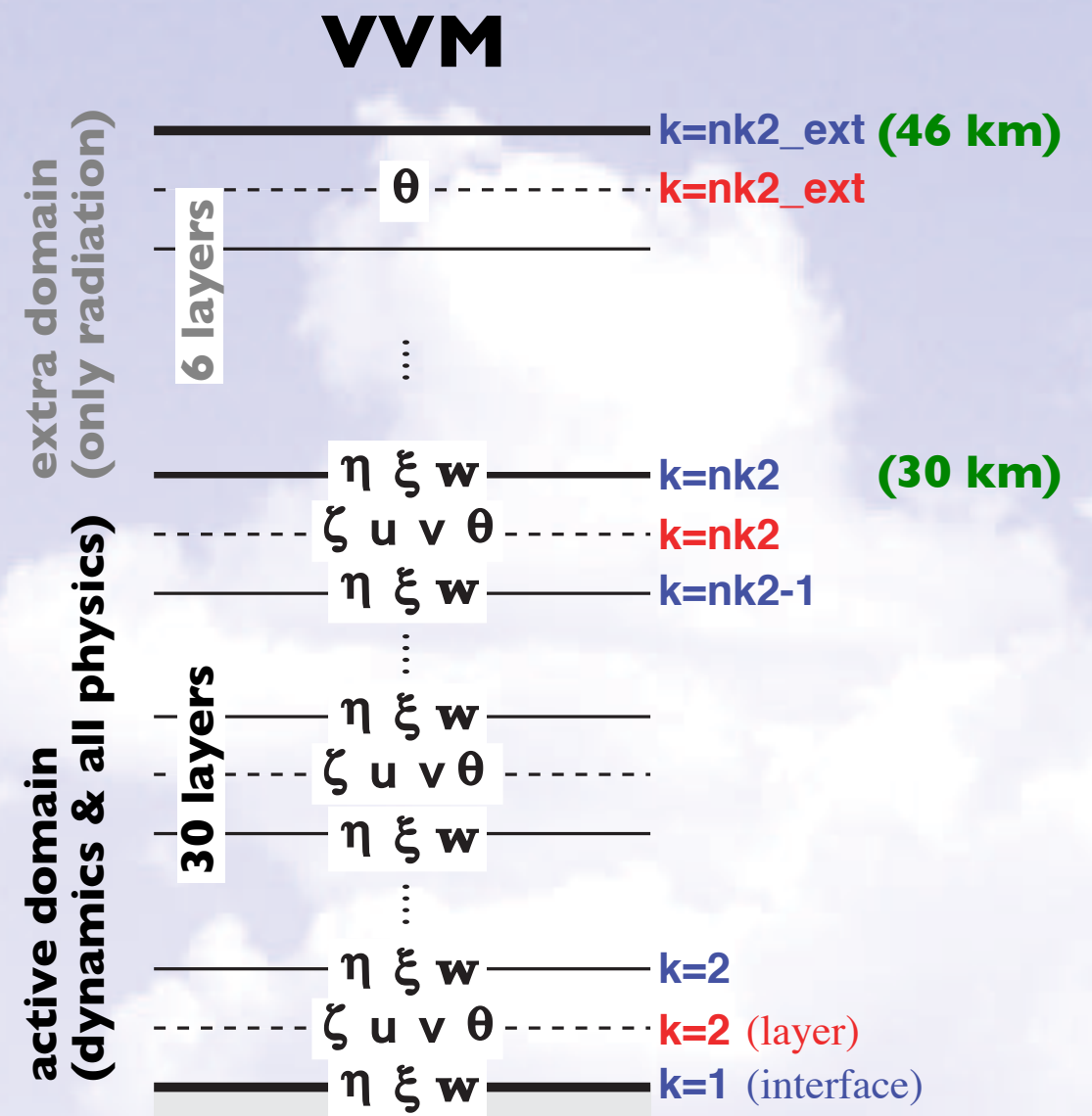
$(dx_{GCM} \sim 100 \text{ km}, dx_{CRM} \sim 4 \text{ km})$       48,600 / 2,430,000



# Vertical Grid Structure of the Q3D MMF



*pressure vertical coordinate  
(hybrid)*

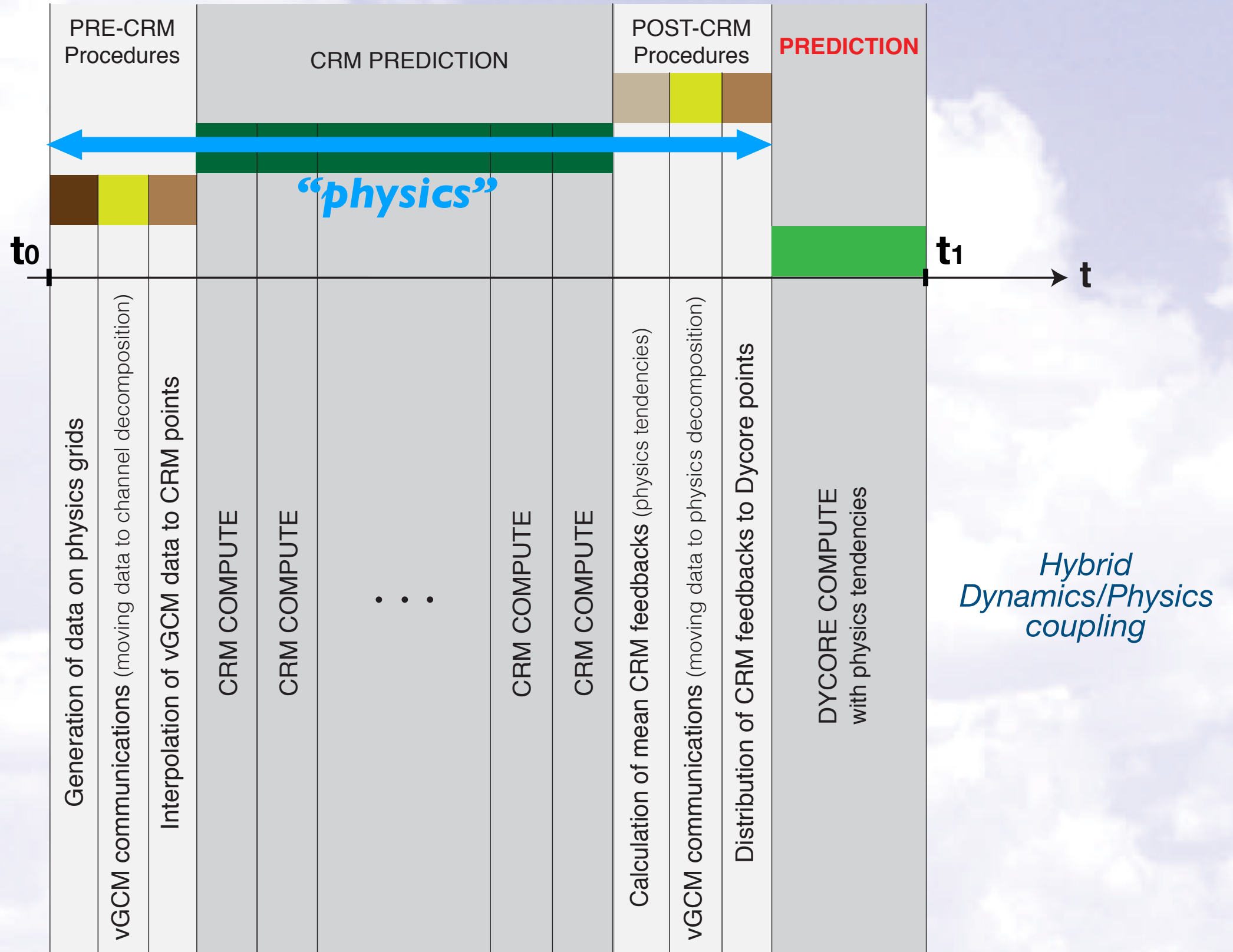


*height vertical coordinate*

*For communication, vertical interpolation is needed.*

# Q3D MMF Computation Algorithm

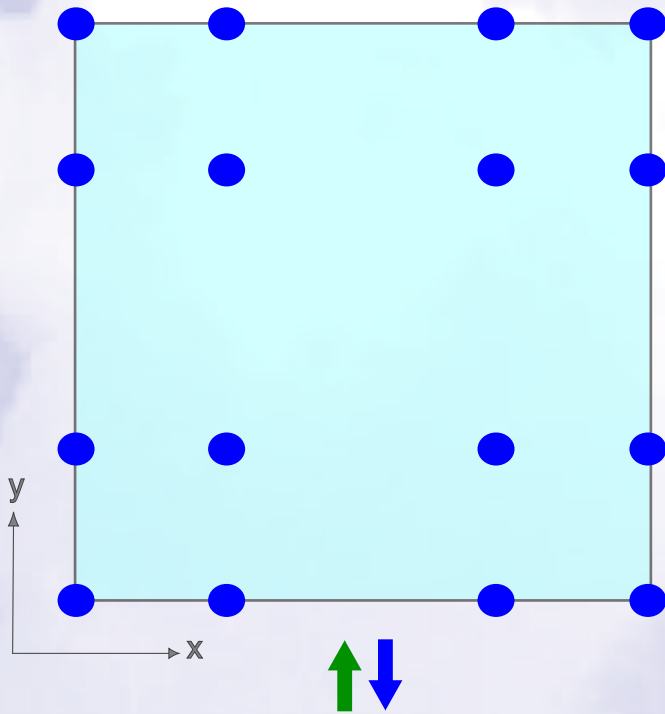
## Similar to the coupling approach of CAM-SE





# Communication between Dycore & CRMs

**GCM *GLL* grid**

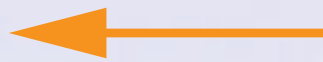


**Two model components are coupled at every GCM time step.**

**“Interface”**

**Output from CRM:**

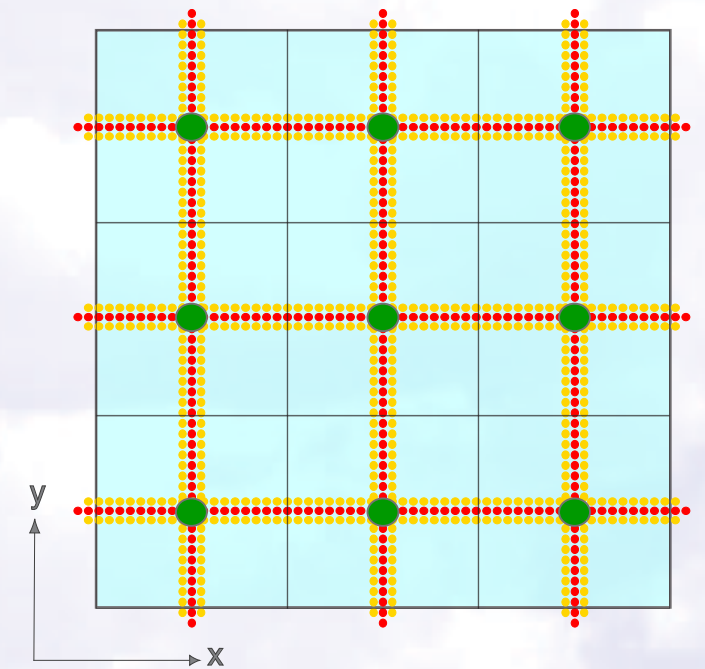
Eddy transport  
& diabatic effects  
*(cell averages)*



**Input to CRM:**

GCM-scale solutions  
interpolated to CRM grids

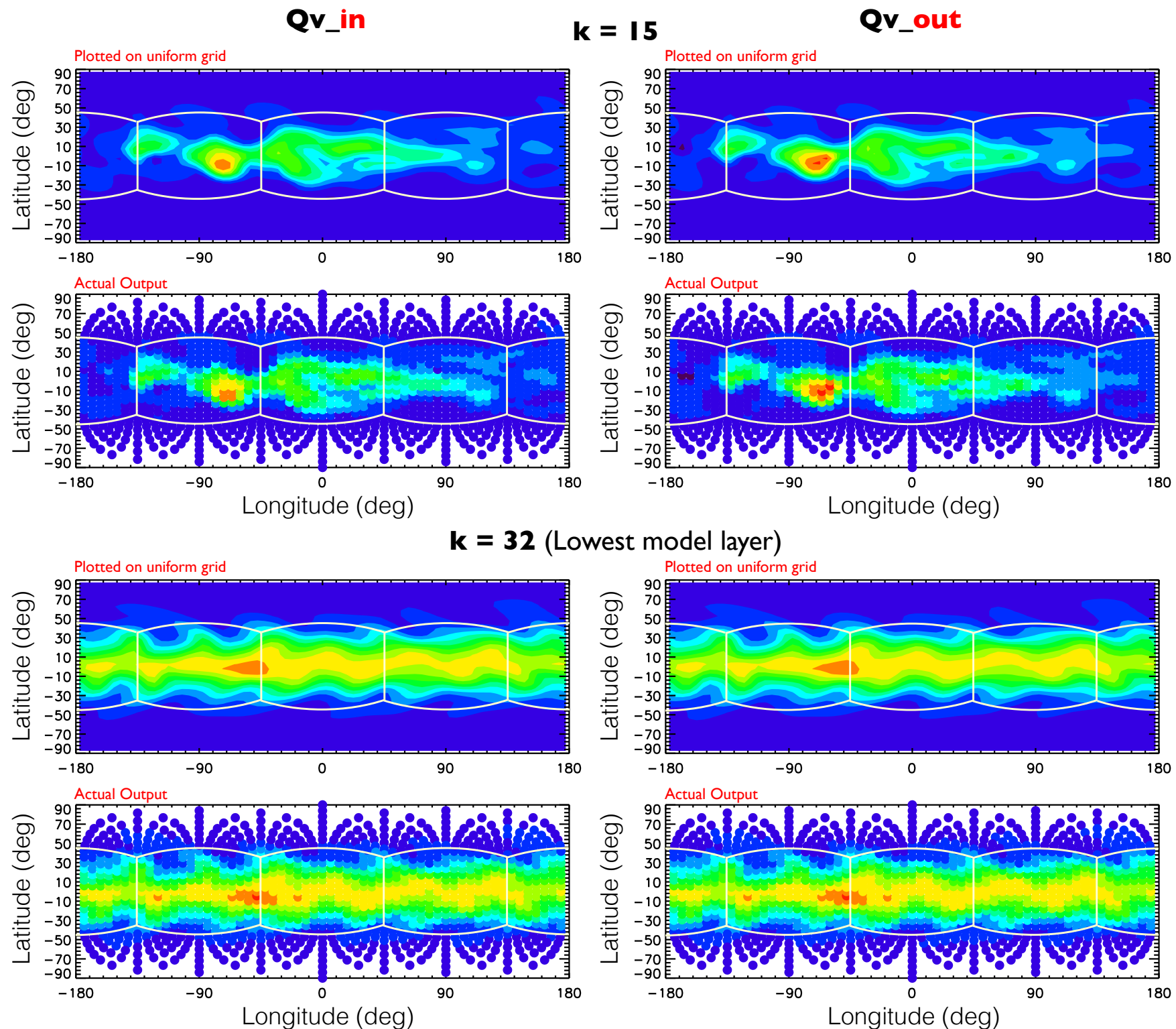
**CRM grid**



**GCM *physics* 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.**



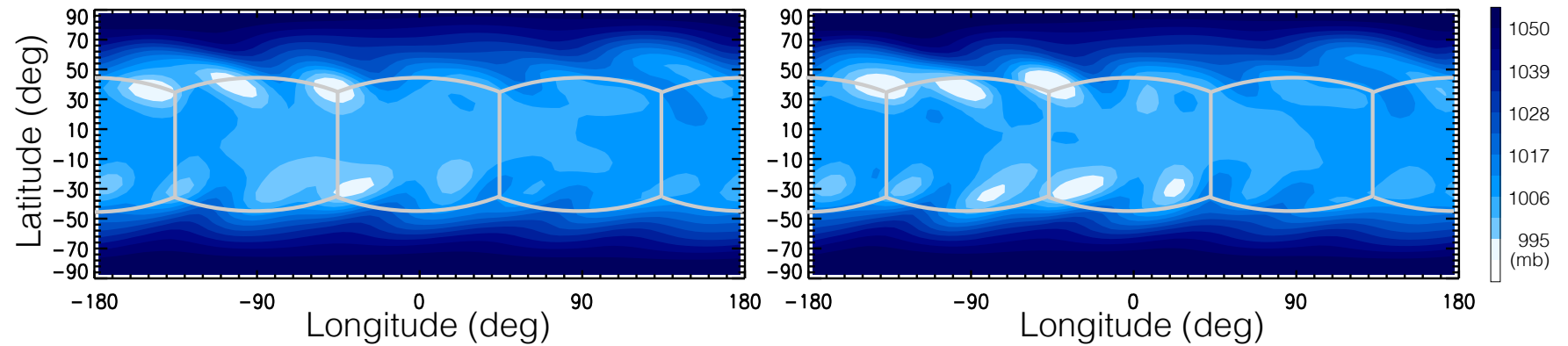
# Short-Term Simulation of the Q3D MMF

t = 0

t = 24 h

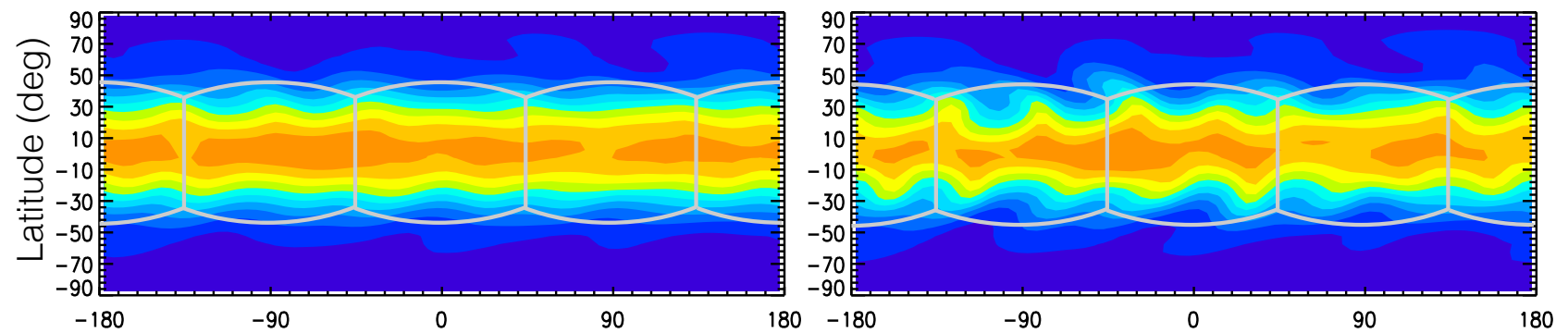
*Without CRM Feedback*

Surface Pressure

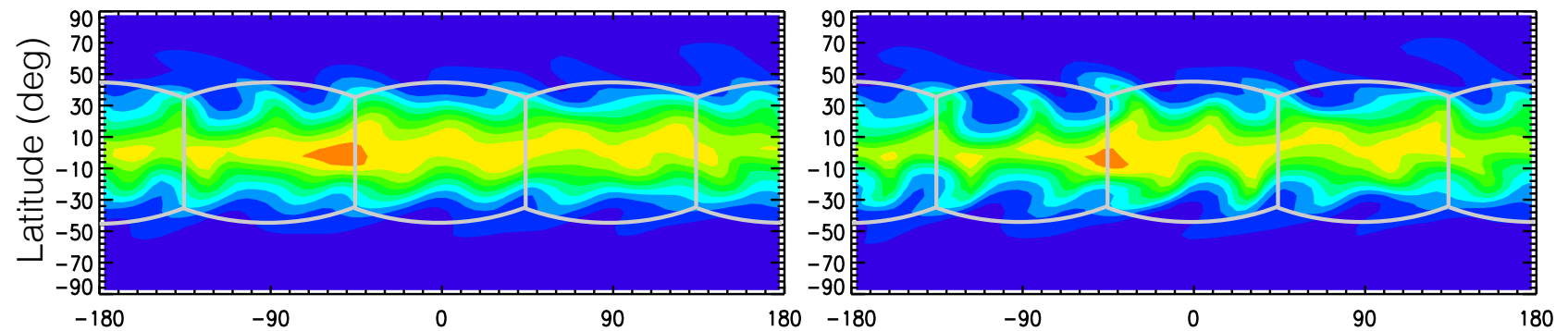


(Lowest model layer)

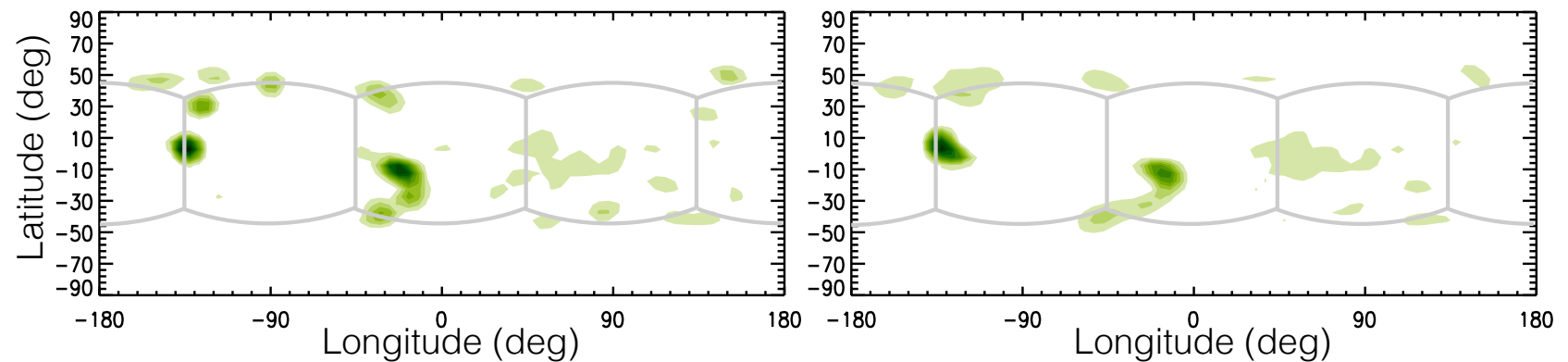
T



Q<sub>v</sub>



Q<sub>r</sub>



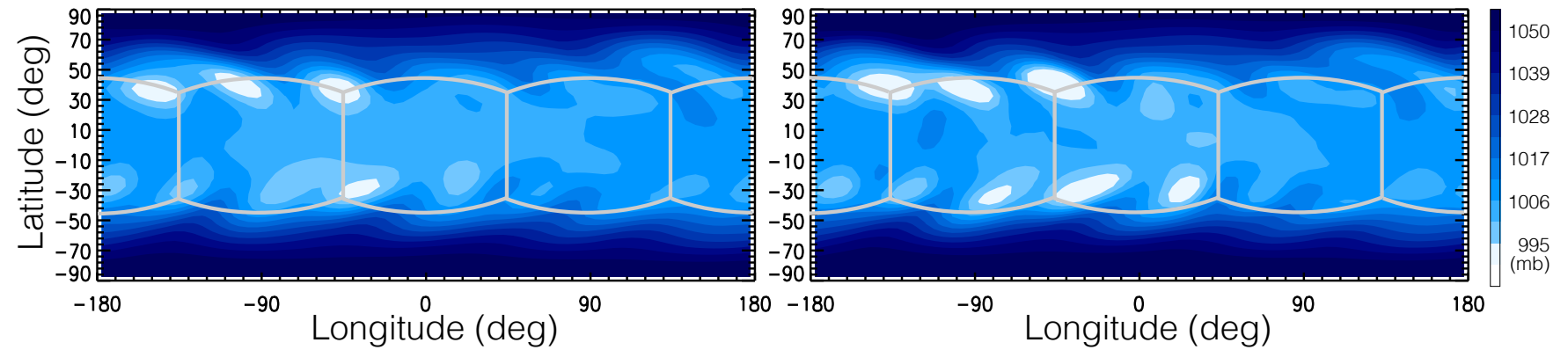
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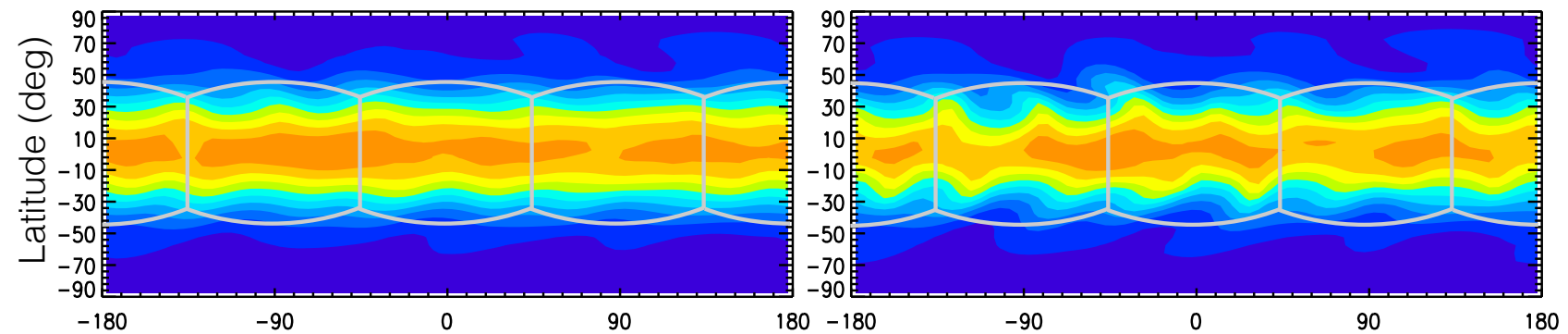
**With CRM Feedback** (Microphysical effect)

Surface Pressure

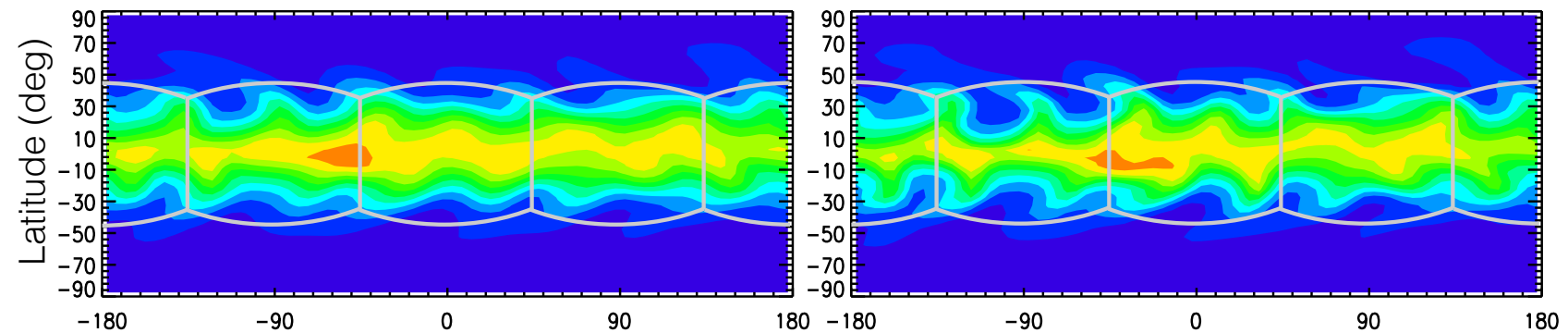


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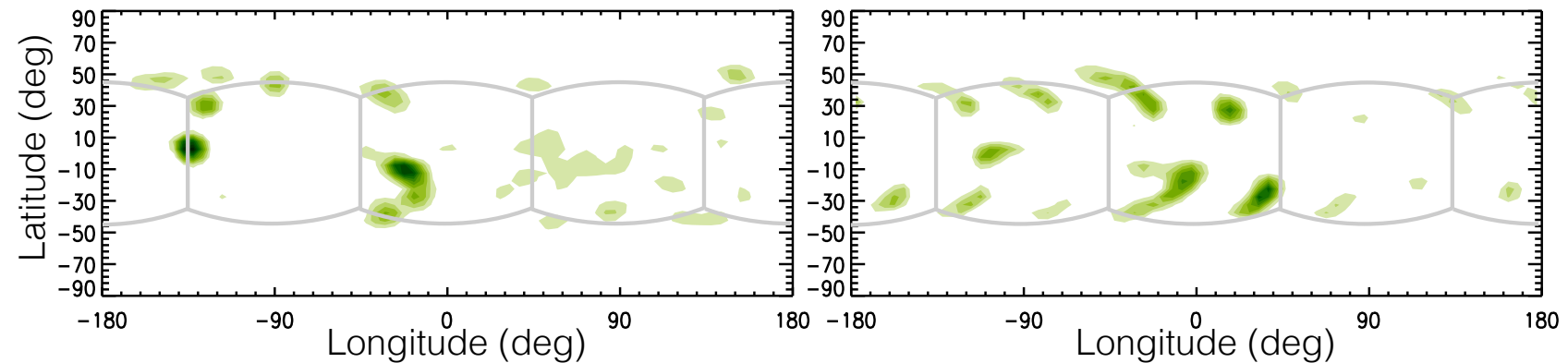
T



$Q_v$



$Q_r$





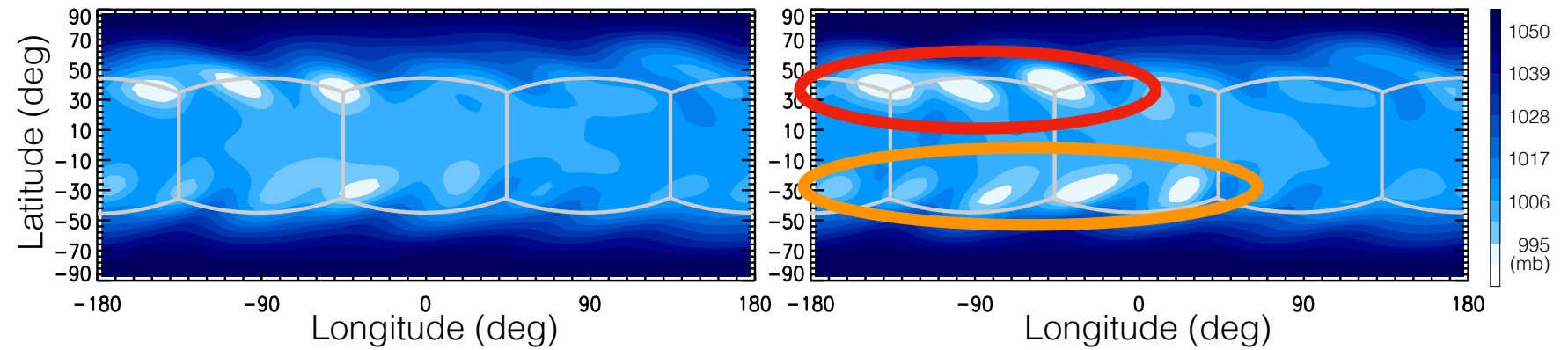
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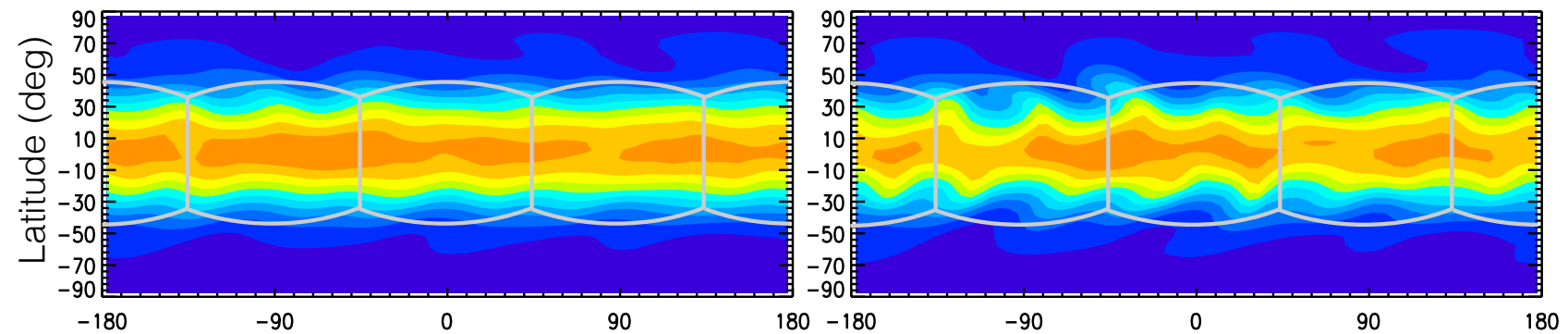
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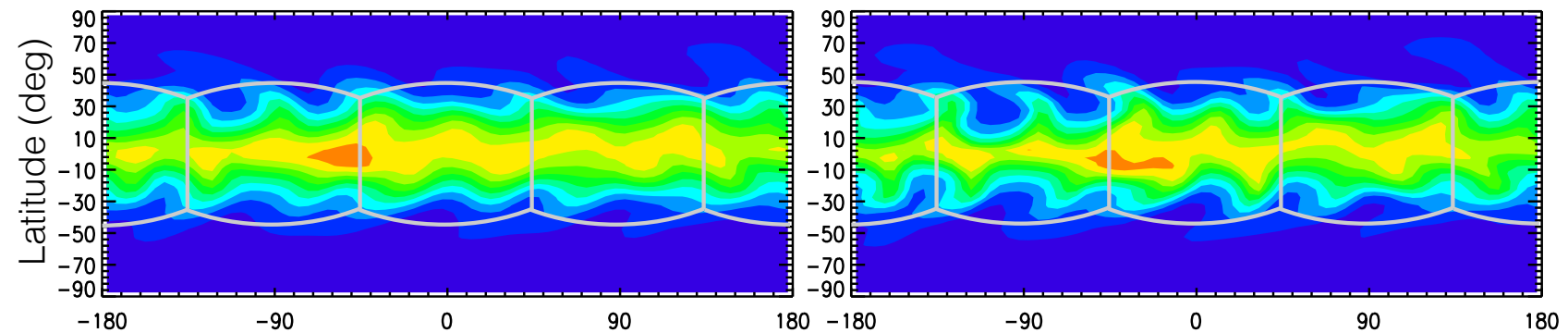


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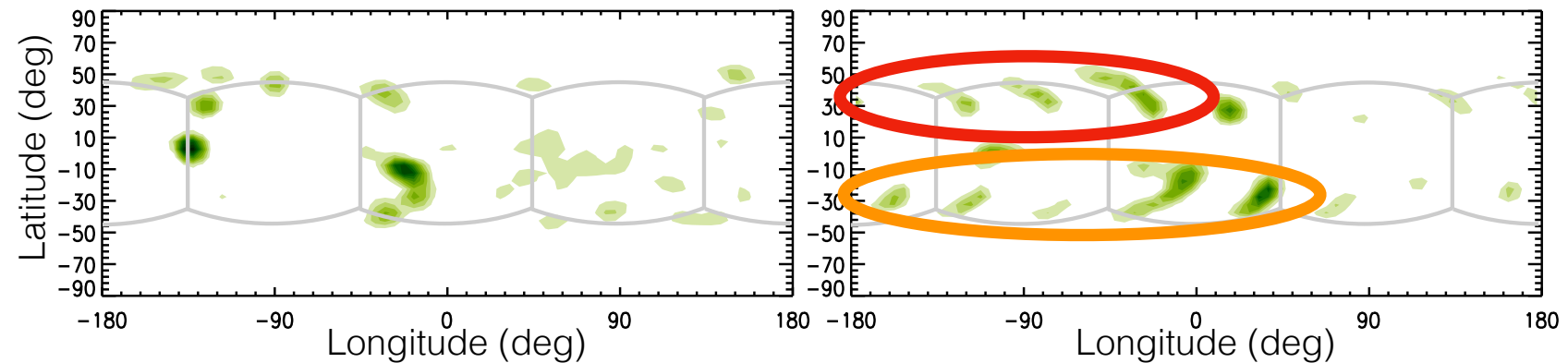
T



$Q_v$



$Q_r$



# 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/cam/branches/Q3D>).
- We are making progress in testing and debugging the new global Q3D MMF with short-term simulations.

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- 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)