Development of a Global Quasi-3-D Multiscale Modeling Framework

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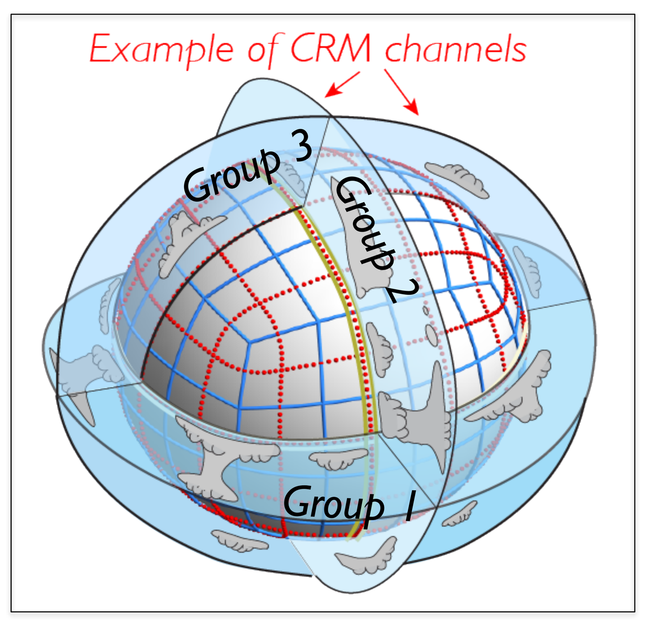
1. Introduction

The Quasi-Three-Dimensional Multiscale Modeling Framework (Q3D MMF) is a second-generation superparameterization, which has been developed with the objective of including cloud-scale effects in a GCM using cloud-resolving models (CRMs). The basic design of the Q3D MMF has been already developed and successfully tested in a limited-area modeling framework. ***Currently, global versions of the Q3D MMF are being created:*** the Spectral Element (SE) cubed-sphere dynamical cores (with CSLAM configuration) of both the CAM and the E3SM *for the GCM component*, and the Vector Vorticity Model (VVM) on cubed-sphere *for the CRM component*.

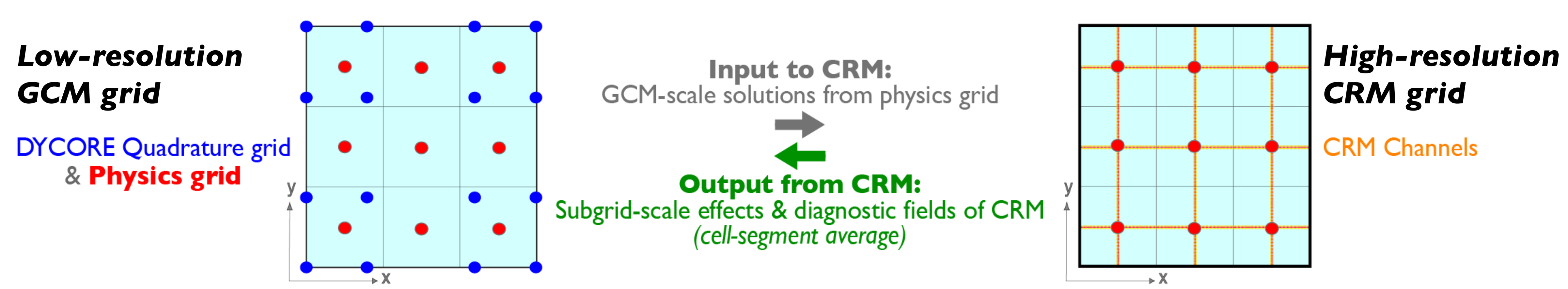
2. Global Q3D MMF



In the Q3D MMF, 1) the CRMs in individual GCM grid columns are seamlessly connected to each other in the form of "channels" that wrap around the planet; 2) two perpendicular channel-segments pass each other (but don't intersect) at the center of each GCM cell; 3) each CRM is formally three-dimensional; and 4) the surface orography can be resolved by the CRMs. There is neither double-counting nor spurious competition between the GCM and CRMs: The GCM feels only eddy transport and diabatic effects from the CRM, and the CRM maintains its GCM grid-scale solution close to GCM's through a relaxation.

The VVM on cubed-sphere: Implementation of the Vector Vorticity Dynamical Core on Cubed Sphere for Use in the Quasi-3-D Multiscale Modeling Framework (J. Adv. Model. Earth Syst., 11, 560-577. https://doi.org/10.1029/2018MS001517)

Horizontal Grid Structure of the Q3D MMF (two grid systems)

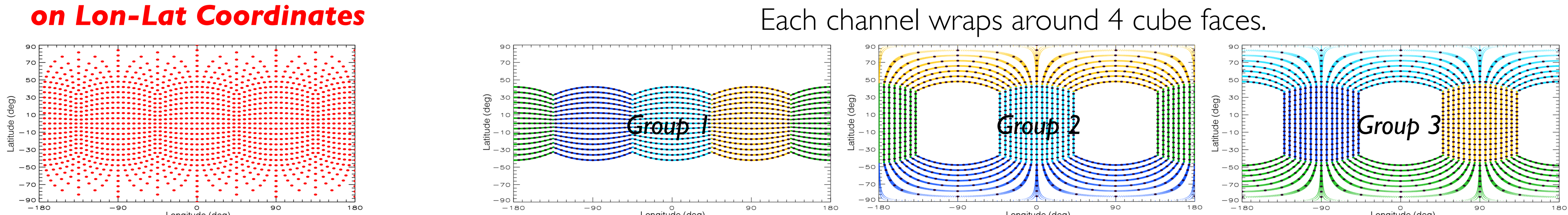


Example of Horizontal Grid Distribution: $N_{phy} = 3, N_e = 5, N_c = 25$ (d_{GCM} ~ 660 km, d_{CRM} ~ 26 km)

Physics grids on Lon-Lat Coordinates

CRM grid channels on Lon-Lat Coordinates

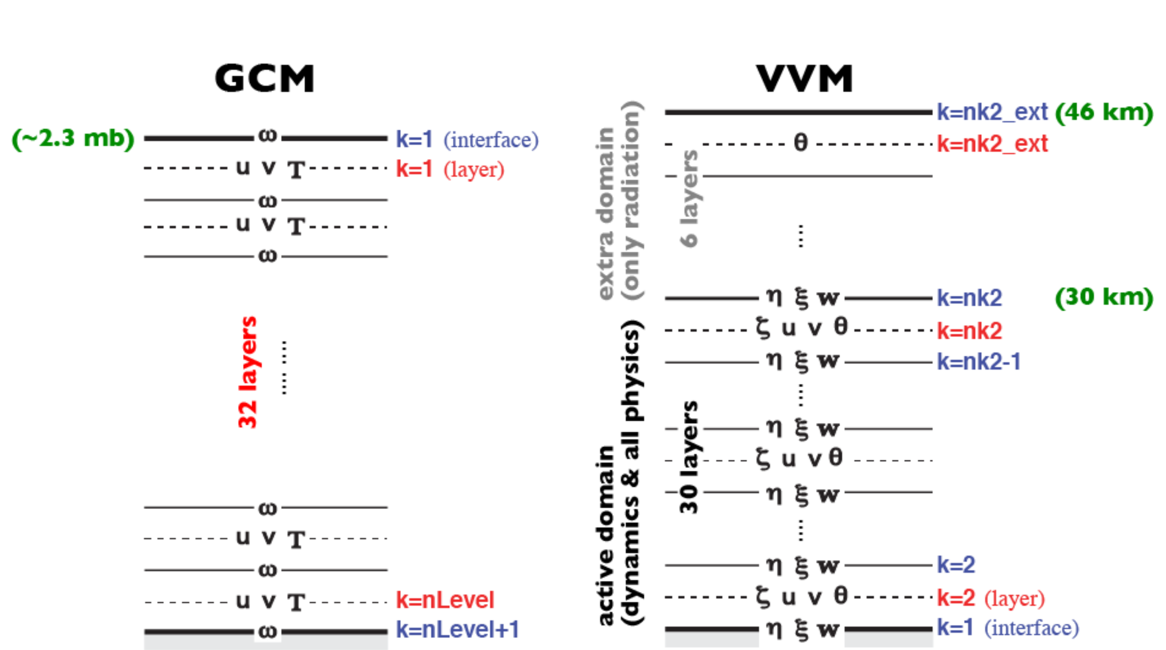
Each channel wraps around 4 cube faces.



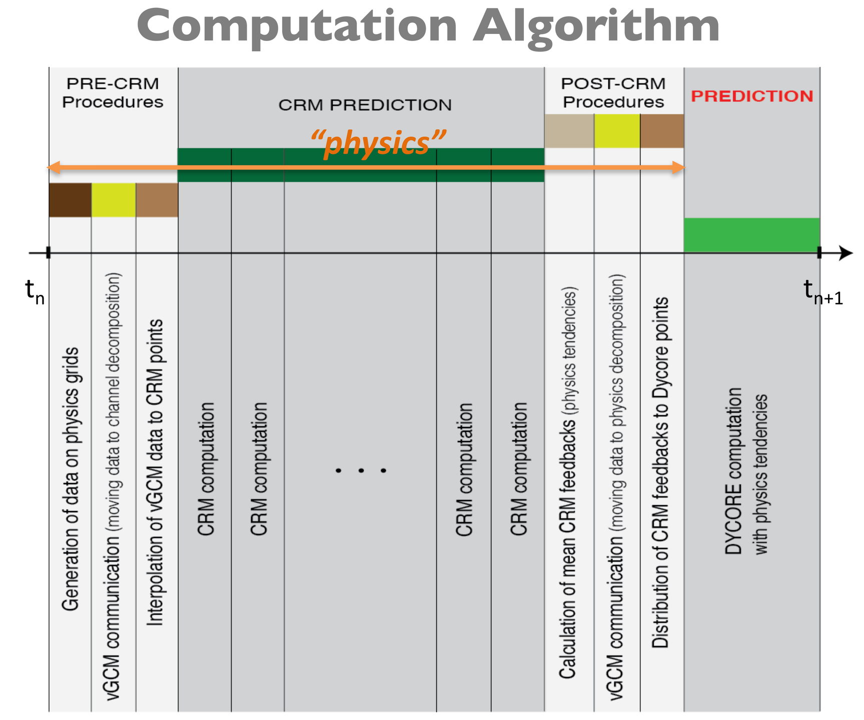
# of physics-grid columns on the globe = $(N_{phy} \times N_e)^2 \times 6$ = 1,350

# of CRM-grid columns on the globe = (# of physics-grid columns) x N_c x 2 = 67,500

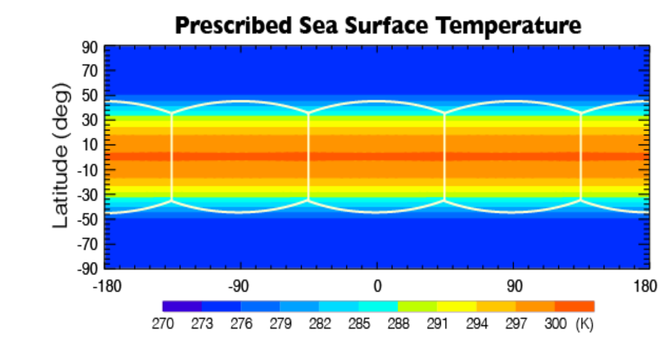
Vertical Grid Structure



Computation Algorithm

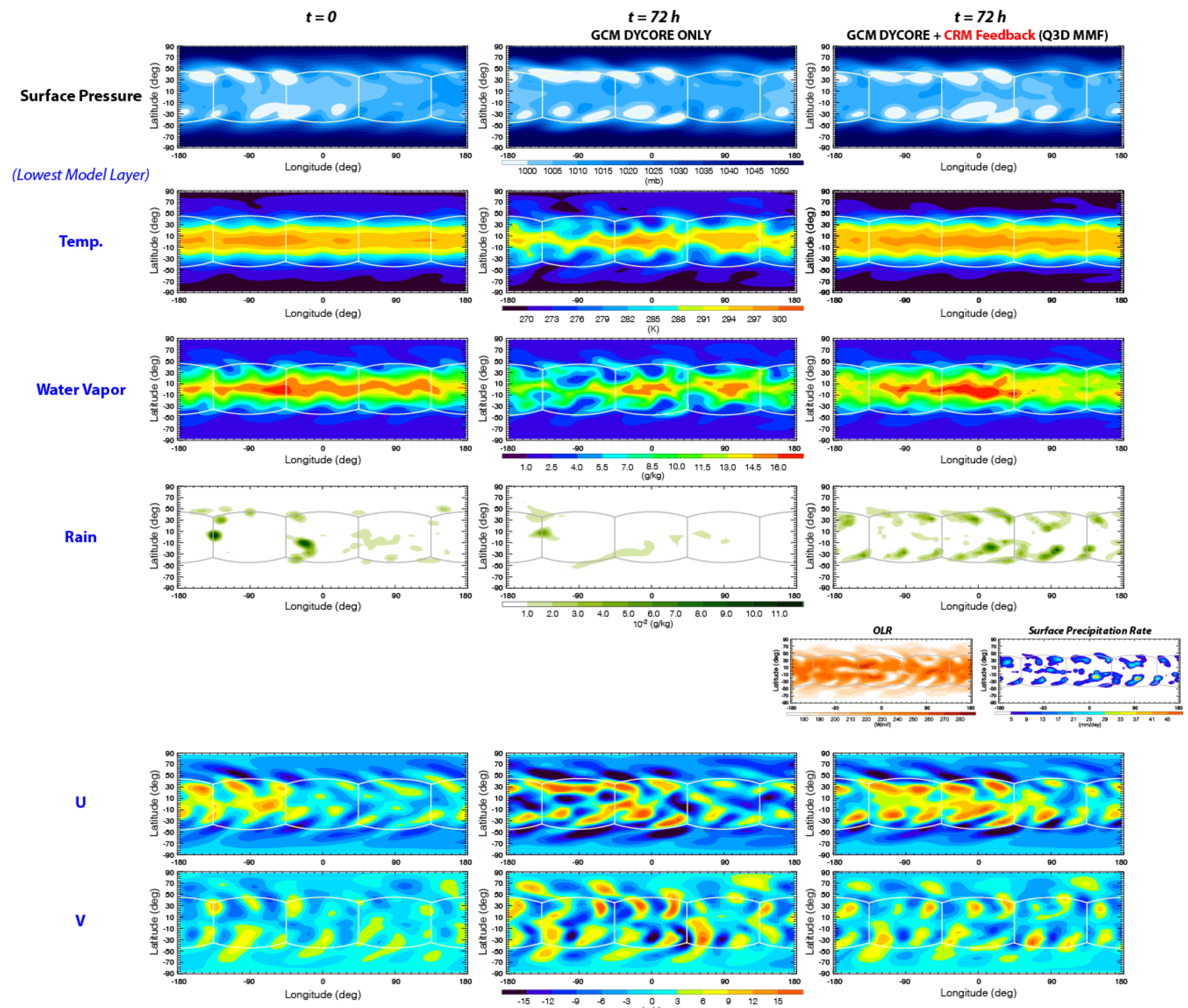


3. Short-term Aqua-planet Simulations



72-h simulations with/without CRM feedbacks:

- GCM grid size ~ 660 km (1,350 columns); CRM grid size ~ 7 km (270,000 columns)
- dt_{GCM} = 10 m; dt_{CRM} = 10 s
- Full physics (radiation, microphysics, turbulence, and surface fluxes) included in the CRMs



In the simulation with CRM feedbacks, the extratropical disturbances intensify during the 72 hours and rain is produced mostly along the fronts.

4. Summary

A version of global Q3D MMF has been created using the CAM-SE-CSLAM DYCORE and is currently being tested with short-term simulations. Another version built on the E3SM is under development. To speed up the computing time of the model, we are in the process of implementing shared-memory parallelism using OpenMP. These models will be evaluated with long-term aqua-planet simulations in the near future.

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