Construction of a Global Geodesic Cloud Resolving Model Based on the Vector Vorticity Dynamical Core

Hexagonal Vector-Vorticity Model (Hex-VVM)

Report on VVM Activities

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A Short Review of Vector-Vorticity Dynamics and Jung-Arakawa Model

Prediction of 3D Vorticity

Horizontal Component:

$$\frac{\partial \boldsymbol{\eta}}{\partial t} = -\nabla \cdot (\boldsymbol{\eta} \mathbf{v}) - \frac{\partial}{\partial z}(\boldsymbol{\eta} w) + \left(\boldsymbol{\eta} \cdot \nabla + \zeta \frac{\partial}{\partial z} \right) \mathbf{v} + \textbf{Buoyancy} + \textbf{Coriolis}_{H}$$

Vertical Component:

$$\frac{\partial \zeta}{\partial t} = -\nabla \cdot (\zeta \mathbf{v}) - \frac{\partial}{\partial z}(\zeta w) + \left(\boldsymbol{\eta} \cdot \nabla + \zeta \frac{\partial}{\partial z} \right) w + \textbf{Coriolis}_{V}$$

Divergence of 3D Vorticity:

$$\nabla \cdot \boldsymbol{\eta} + \frac{\partial \zeta}{\partial z} = 0$$

Continuity Equation (Anelastic Approximation)

$$\nabla \cdot \mathbf{v} + \frac{1}{\rho_0}\frac{\partial}{\partial z}\left(\rho_0 w\right) = 0$$

Vector-Vorticity Model (VVM)
Jung and Arakawa (2008)

①- Derives and solves an elliptic equation for vertical velocity (w)

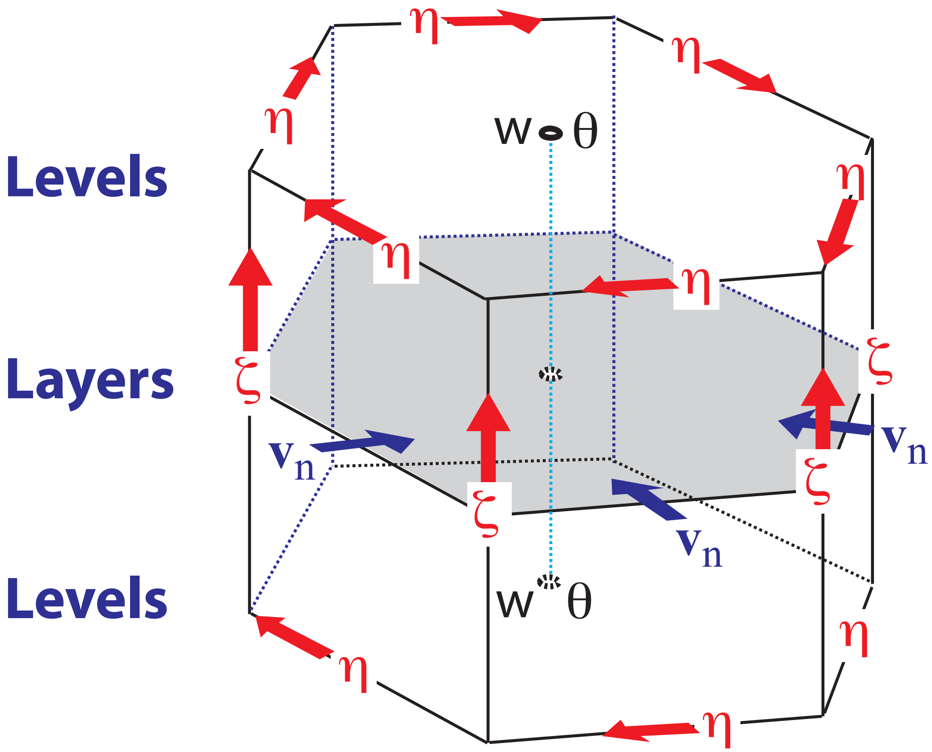
②- Obtains horizontal velocity (**v**) by vertically integrating η and using w (by using a proper boundary condition for **v**)

③- Obtains ζ by vertically integrating the divergence of 3D vorticity (after predicting ζ at a particular height)

4- These calculations are made on Cartesian coordinates

Hexagonal Vector-Vorticity Model (Hex-VVM)

3-D view of the interior grid



Non-Buoyant Bubble Case
Prediction of 3D Vorticity

Horizontal Component:

$$\frac{\partial \boldsymbol{\eta}}{\partial t} = -\nabla\cdot(\boldsymbol{\eta}\mathbf{v}) - \frac{\partial}{\partial z}(\boldsymbol{\eta}w) + \left(\boldsymbol{\eta}\cdot\nabla + \zeta\frac{\partial}{\partial z}\right)\mathbf{v} + \mathbf{B}\text{uoyancy} + \mathbf{C}\text{oriolis}_H$$

Vertical Component:

$$\frac{\partial \zeta}{\partial t} = -\nabla\cdot(\zeta\mathbf{v}) - \frac{\partial}{\partial z}(\zeta w) + \left(\boldsymbol{\eta}\cdot\nabla + \zeta\frac{\partial}{\partial z}\right)w + \mathbf{C}\text{oriolis}_V$$

Continuity Equation:

$$\nabla\cdot\mathbf{v} + \frac{1}{\rho_0}\frac{\partial}{\partial z}(\rho_0 w) = 0$$

Divergence of 3D Vorticity:

$$\nabla\cdot\boldsymbol{\eta} + \frac{\partial \zeta}{\partial z} = 0$$

Procedure

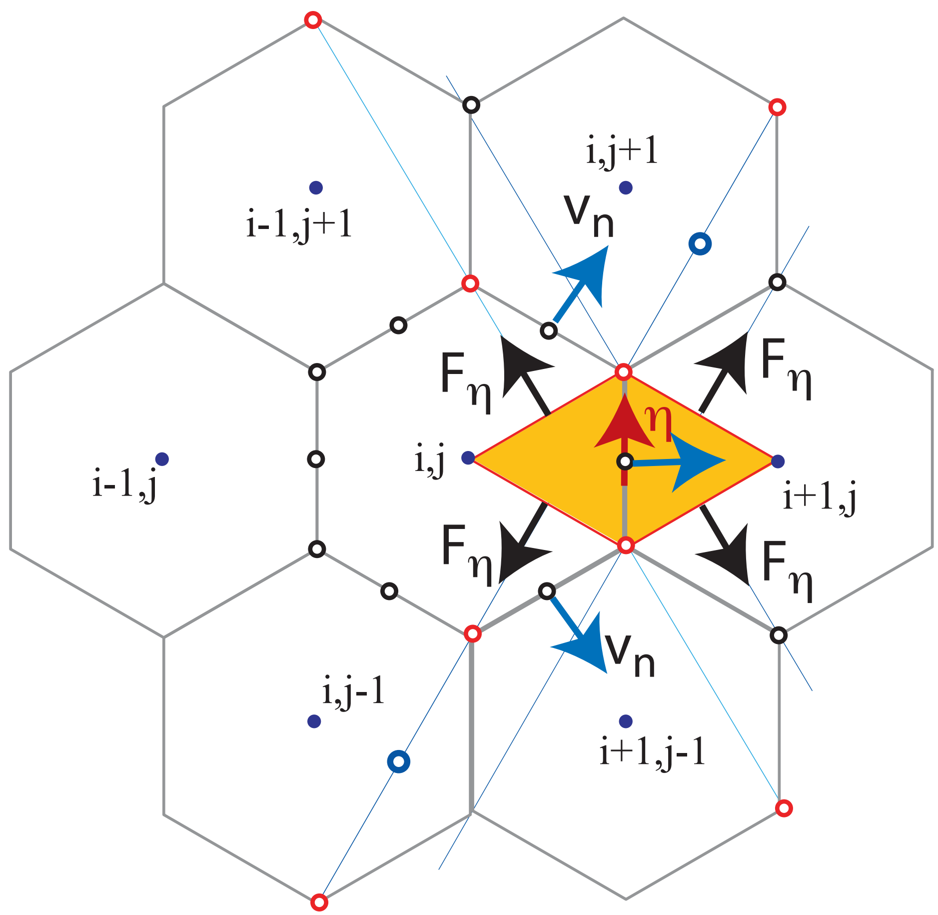
①- Solve an elliptic equation for vertical velocity (w) (works well)

2 - Obtain horizontal velocity (**v**) by vertically integrating η and using w (by using a proper boundary condition for **v**) (does't work well)

Alternative②- Solve the continuity equation for **v** using w

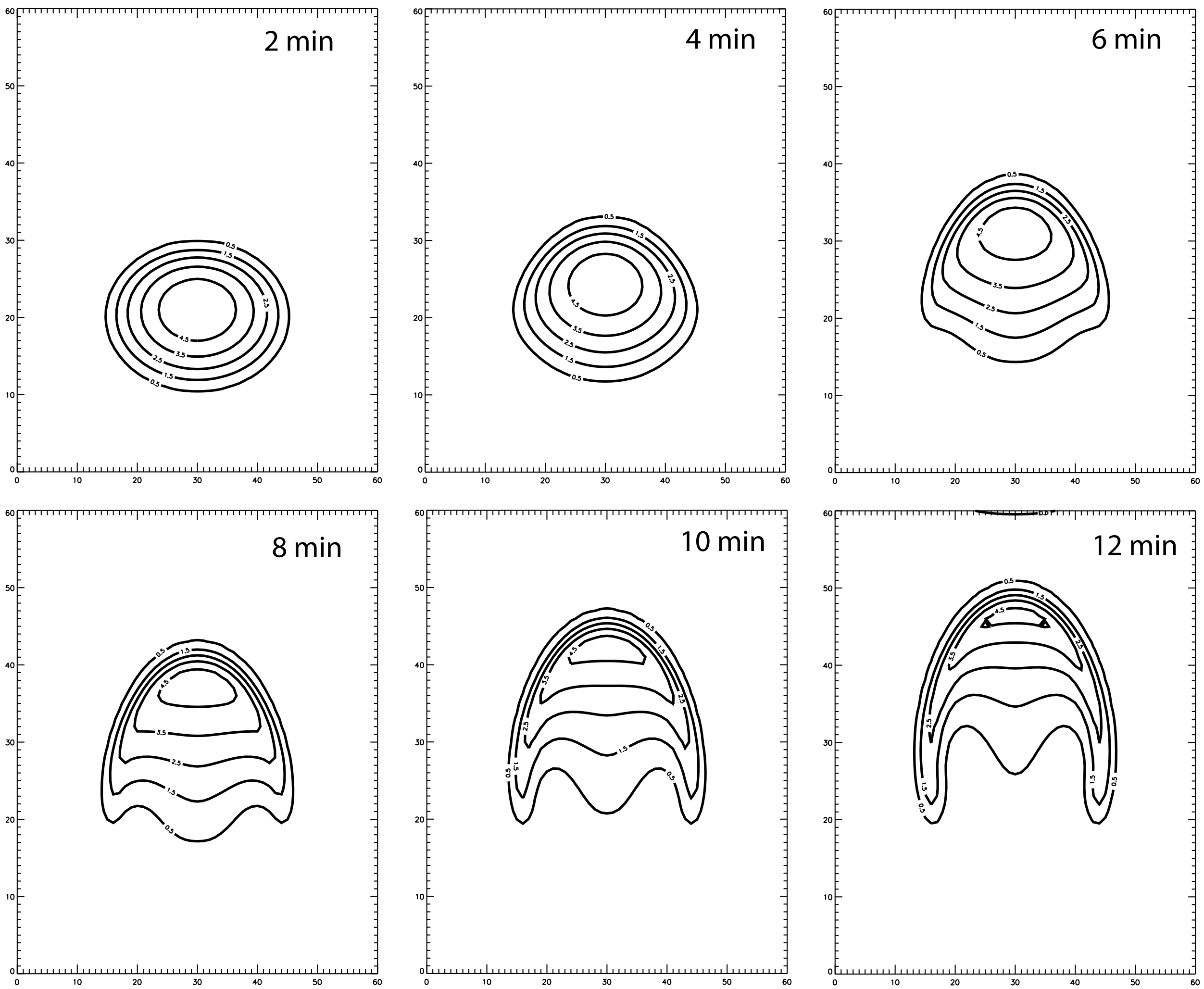
③- ~~Obtain ξ by vertically integrating the divergence of 3D vorticity (after predicting ξ at a particular height)~~

Horizontal η Fluxes



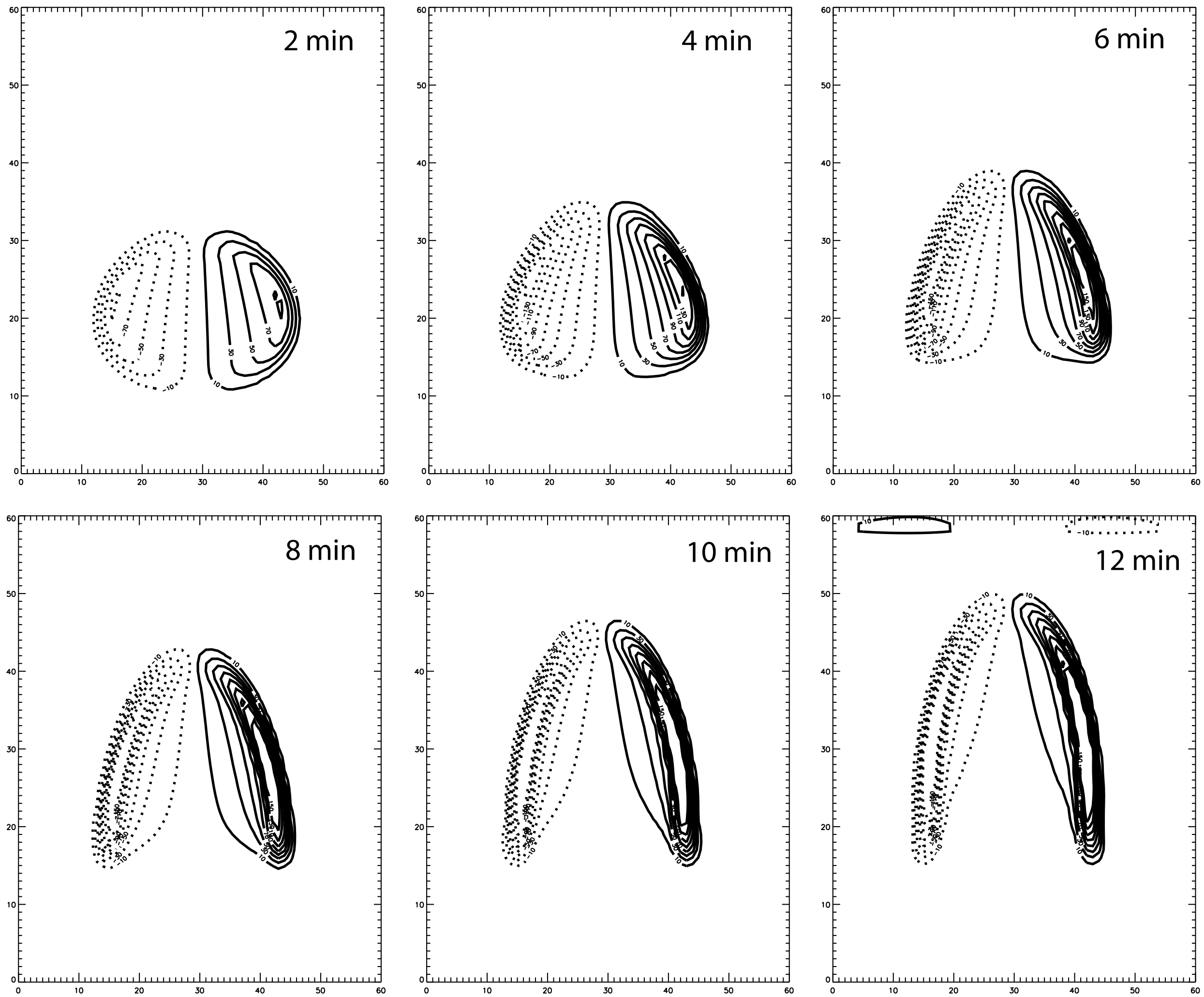
Non-Buoyant Bubble Experiment with Hex-VVM (an earlier result)

(Potential Temperature (Deg) / Passive Tracer)



Non-Buoyant Bubble Experiment with Hex-VVM (an earlier result)

(Horizontal Component of Vorticity, η, 10^{-4} sec^{-1})



Revised Equations

Horizontal Component:

$$\frac{\partial \boldsymbol{\eta}}{\partial t} = -\mathbf{v}\cdot\nabla\boldsymbol{\eta} - w\frac{\partial \boldsymbol{\eta}}{\partial z} + \left(\frac{1}{\rho_0}\frac{\partial \rho_0}{\partial z}\right)\boldsymbol{\eta} w + \left(\boldsymbol{\eta}\cdot\nabla\right)\mathbf{v}$$

Continuity Equation:

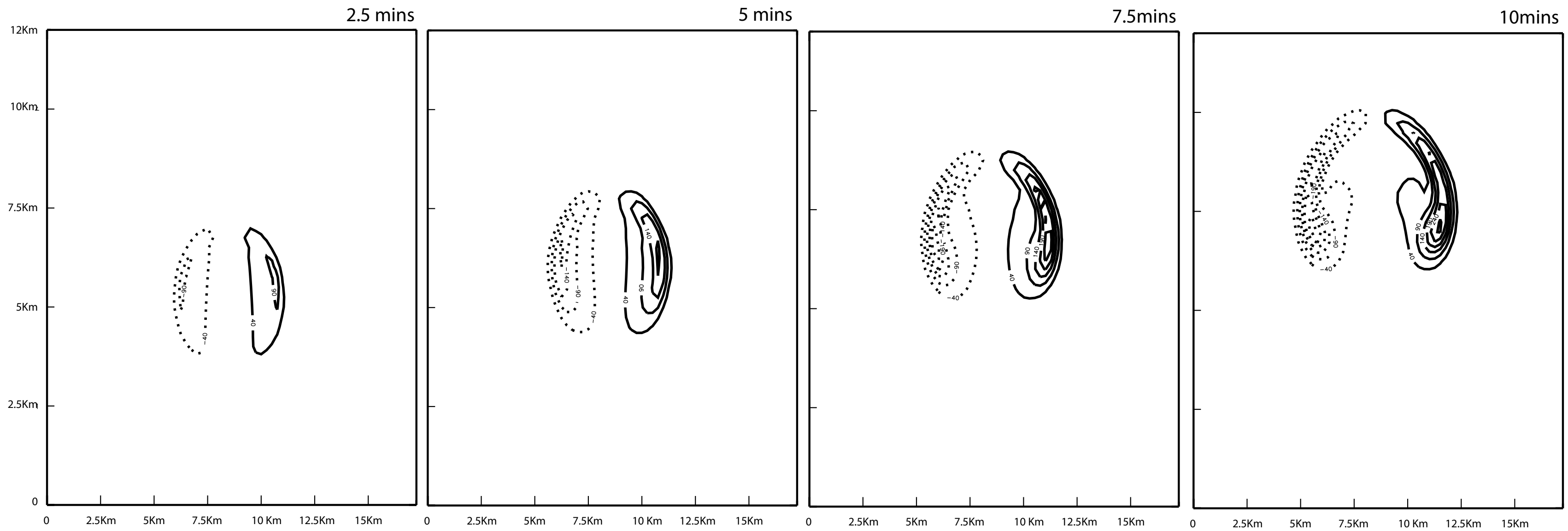
$$\nabla\cdot\mathbf{v} + \frac{1}{\rho_0}\frac{\partial}{\partial z}\left(\rho_0 w\right) = 0$$

Horizontal Divergence of Horizontal Component of Vorticity:

$$\nabla\cdot\boldsymbol{\eta} = 0$$

Buoyant Bubble Experiment with Hex-VVM

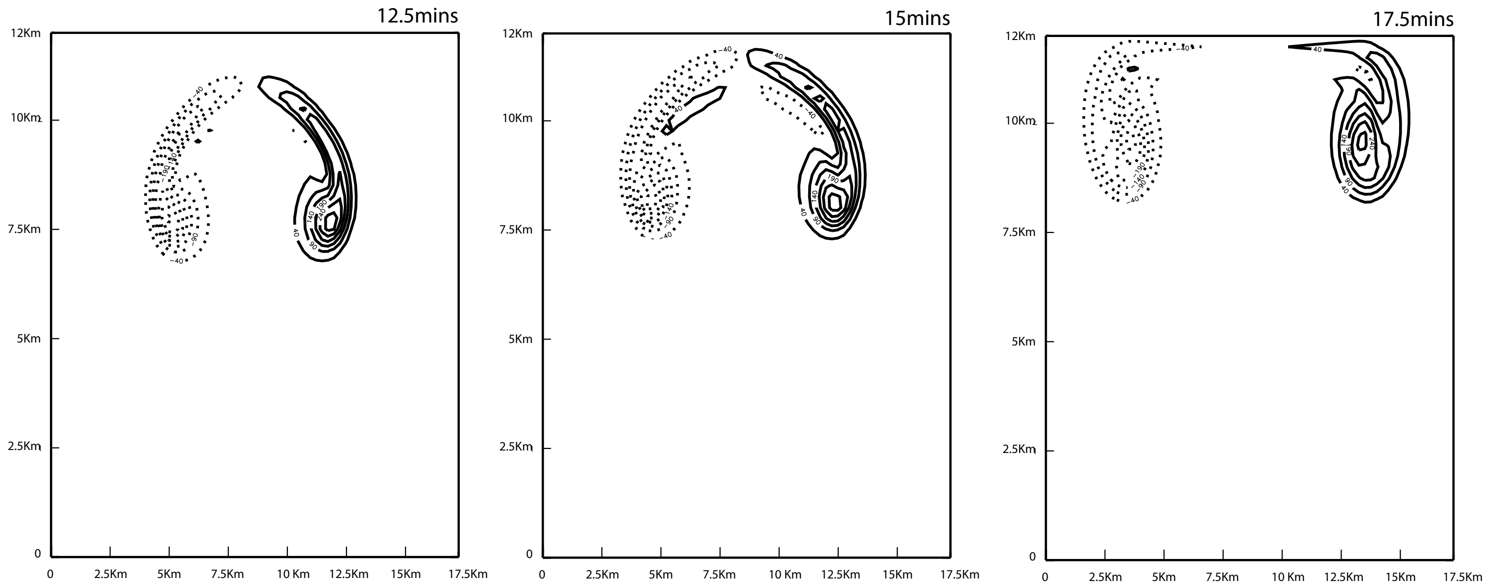
(Horizontal Component of Vorticity, η, 10^{-4} sec^{-1})



Exp75.4

Buoyant Bubble Experiment with Hex-VVM

(Horizontal Component of Vorticity, η, 10^{-4} sec^{-1})



Exp75.4

Procedure

① - Solve an elliptic equation for vertical velocity (w)

2 - Obtain horizontal velocity (**v**) by vertically integrating η and using w (by using a proper boundary condition for **v**) (use it's alternative)

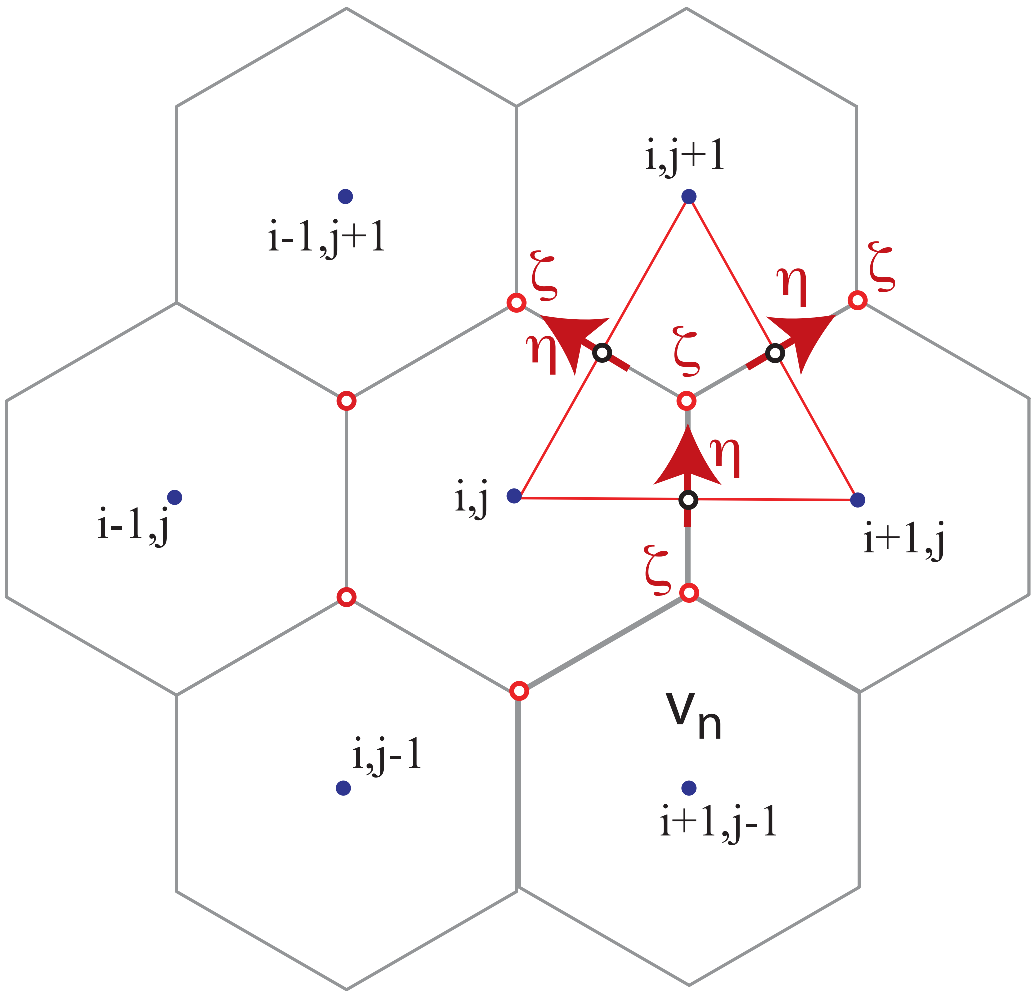
② - Solve the continuity equation for **v** using w

③ - Obtain ζ by vertically integrating the divergence of 3D vorticity (after predicting ζ at a particular height) (doesn't work well)

Divergence of 3D Vorticity:

$$\nabla \cdot \boldsymbol{\eta} + \frac{\partial \zeta}{\partial z} = 0$$

Distribution of η and ζ



Procedure

①- Solve an elliptic equation for vertical velocity (w)

2 - Obtain horizontal velocity (**v**) by vertically integrating η and using w (by using a proper boundary condition for **v**) (use it's alternative)

②- Solve the continuity equation for **v** using w

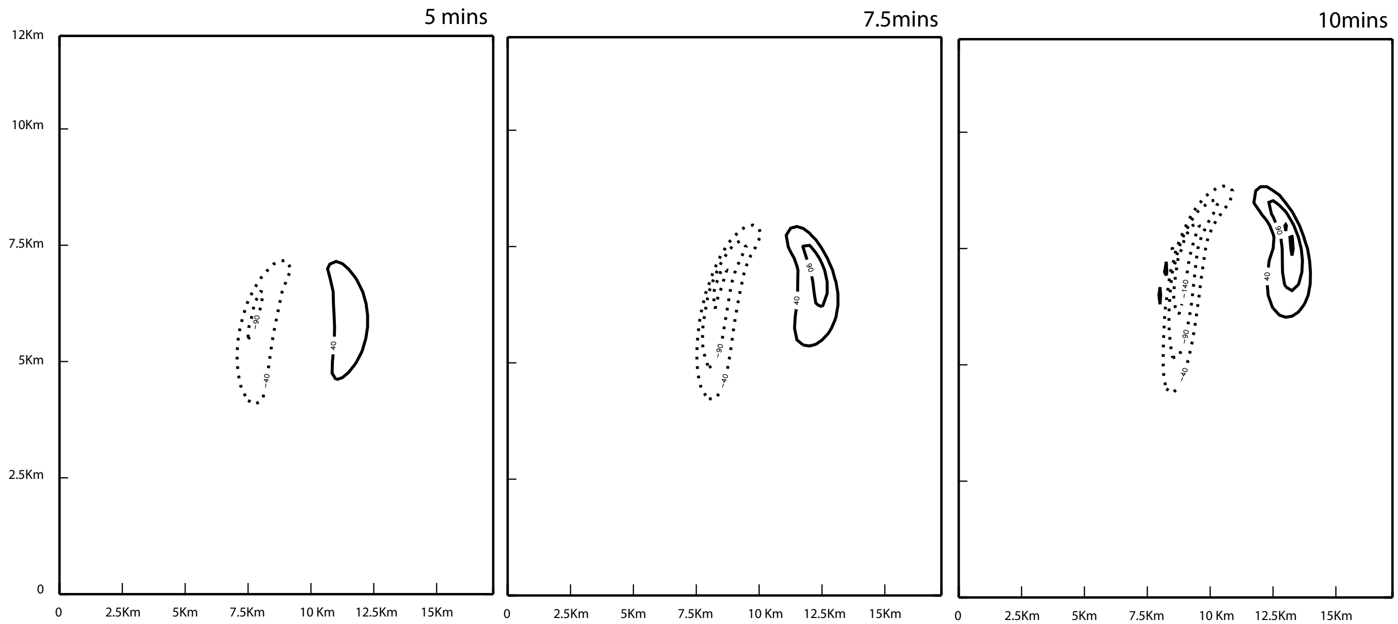
3 - Obtain ζ by vertically integrating the divergence of 3D vorticity (after predicting ζ at a particular height) (doesn't work well)

Alternative③- Predict ζ for each layer

Buoyant Bubble Experiment with Hex-VVM

Under Constant Westerly Shear (8.3×10^{-4} sec^{-1})

(Horizontal Component of Vorticity, η', 10^{-4} sec^{-1})

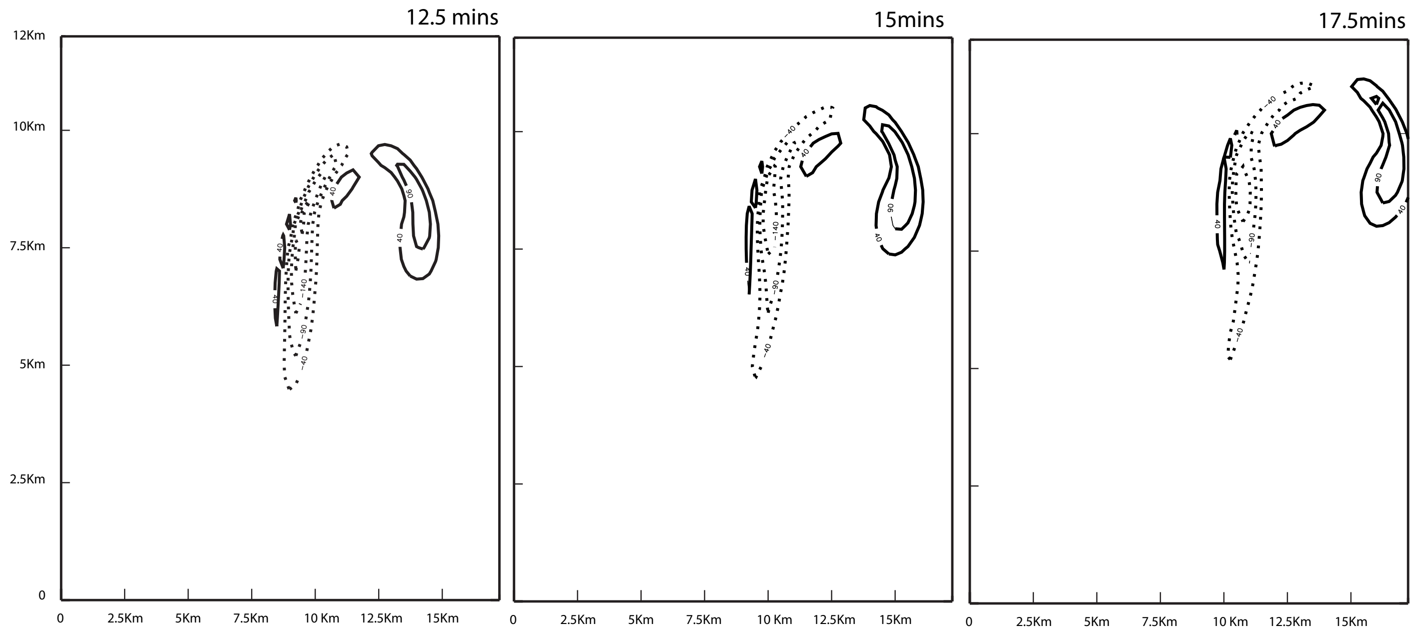


Exp75.7.1nn

Buoyant Bubble Experiment with Hex-VVM

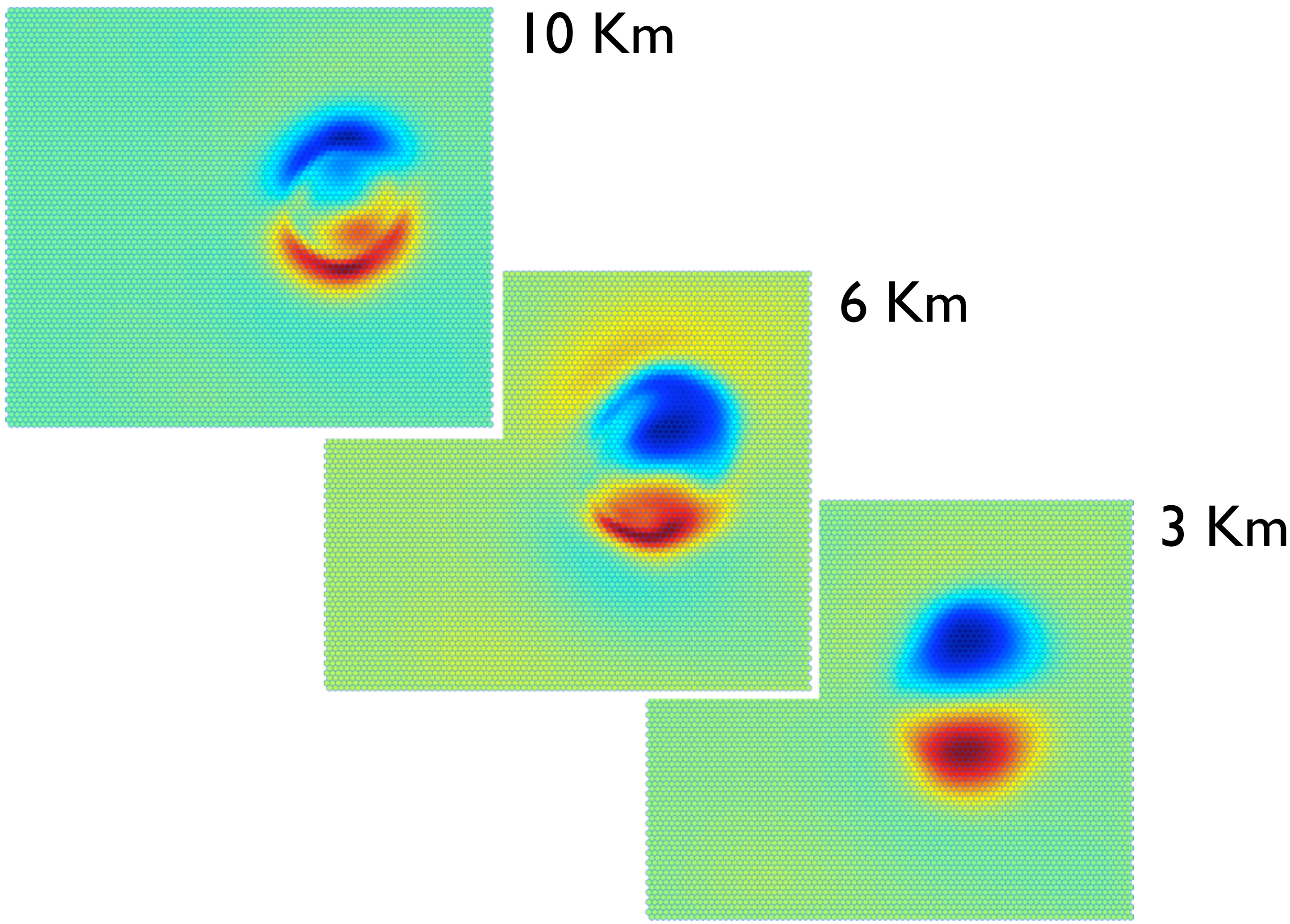
Under Constant Westerly Shear (8.3×10^{-4} sec^{-1})

(Horizontal Component of Vorticity, η', 10^{-4} sec^{-1})



Exp75.7.1nn

Vertical Vorticity for Different Layers (15mins)



Max and mins is approximately $10 \bullet 10^{-4} \mathrm{sec}^{-1}$.

Conclusions

1 - Elliptic solver is validated

2 - Satisfaction of the mass continuity for cell centers is examined and verified

3 - Yet maintenance of the mass continuity for cell walls (and presumably for cell corners) are found to be problematic

4 - To cure this problem, "advective" form is used

5 - There are still remaining problems with the integration procedure

Report on VVM Activities

1 - Code development of VVM (with parallelized code) is completed

2 - Simulations with GATE Phase III forcing are underway

3 - CAM radiation is implemented as an option

4 - Work on the implementation of RRTMG radiation code is still continuing