Numerical simulations of orographic locking of precipitation in an idealized typhoon environment

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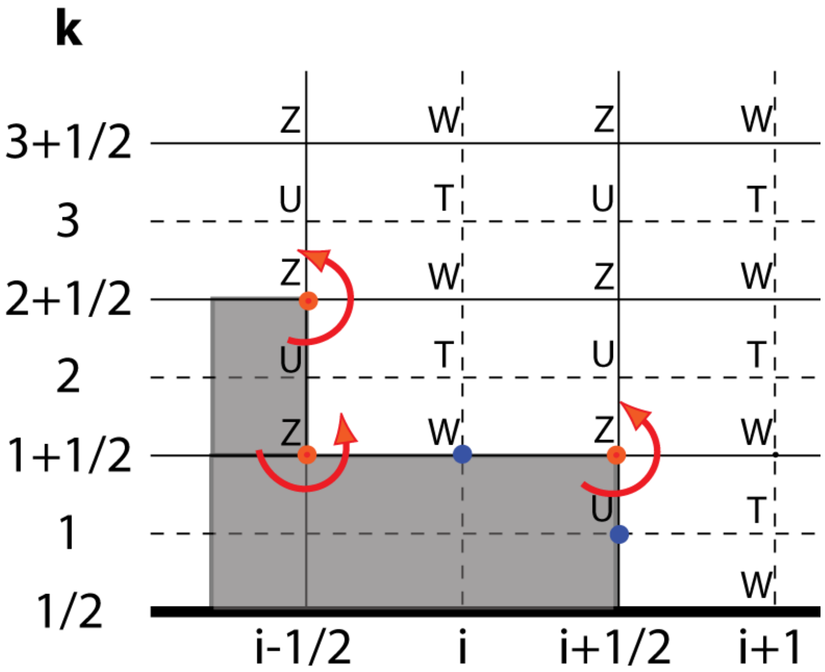
The block mountain approach in VVM

Topography is implemented by using direct forcing at the mountain corners

- The strength of the vorticity at the corners is determined through vorticity definition.

$$\boxed{\eta_b = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \qquad u_b = w_b = 0}$$



$$(\eta_b)_{i,1+1/2} =$$

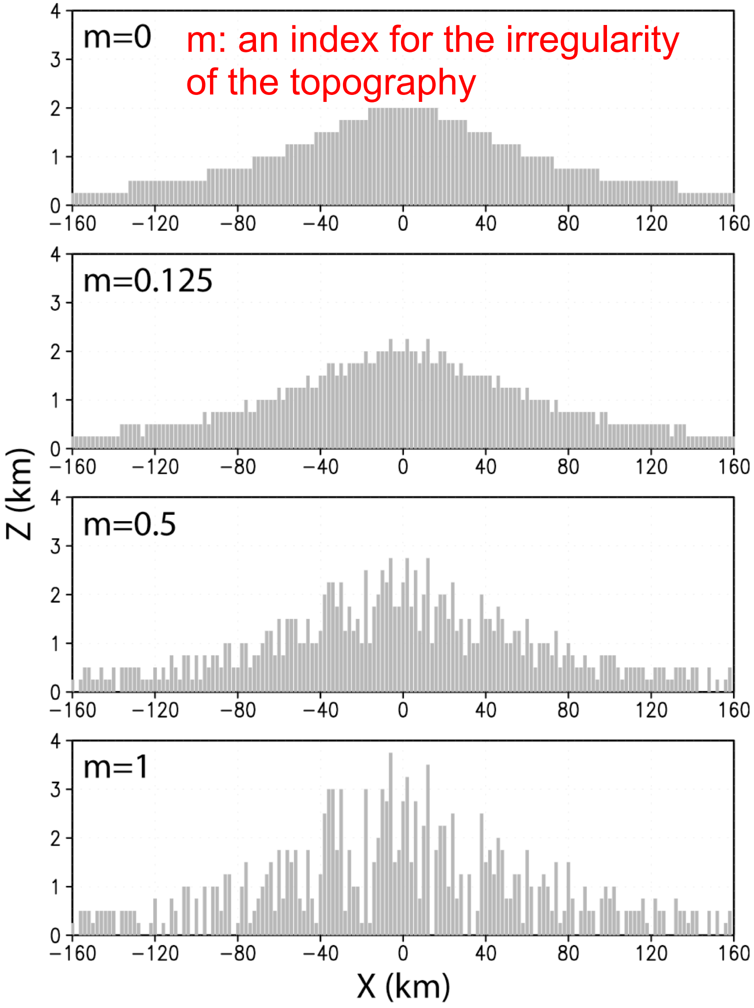
$$\frac{u_{i,2} - \underline{(u_b)_{i,1}}}{\Delta z} - \frac{w_{i+1/2,1+1/2} - \underline{(w_b)_{i-1/2,1+1/2}}}{\Delta x}$$

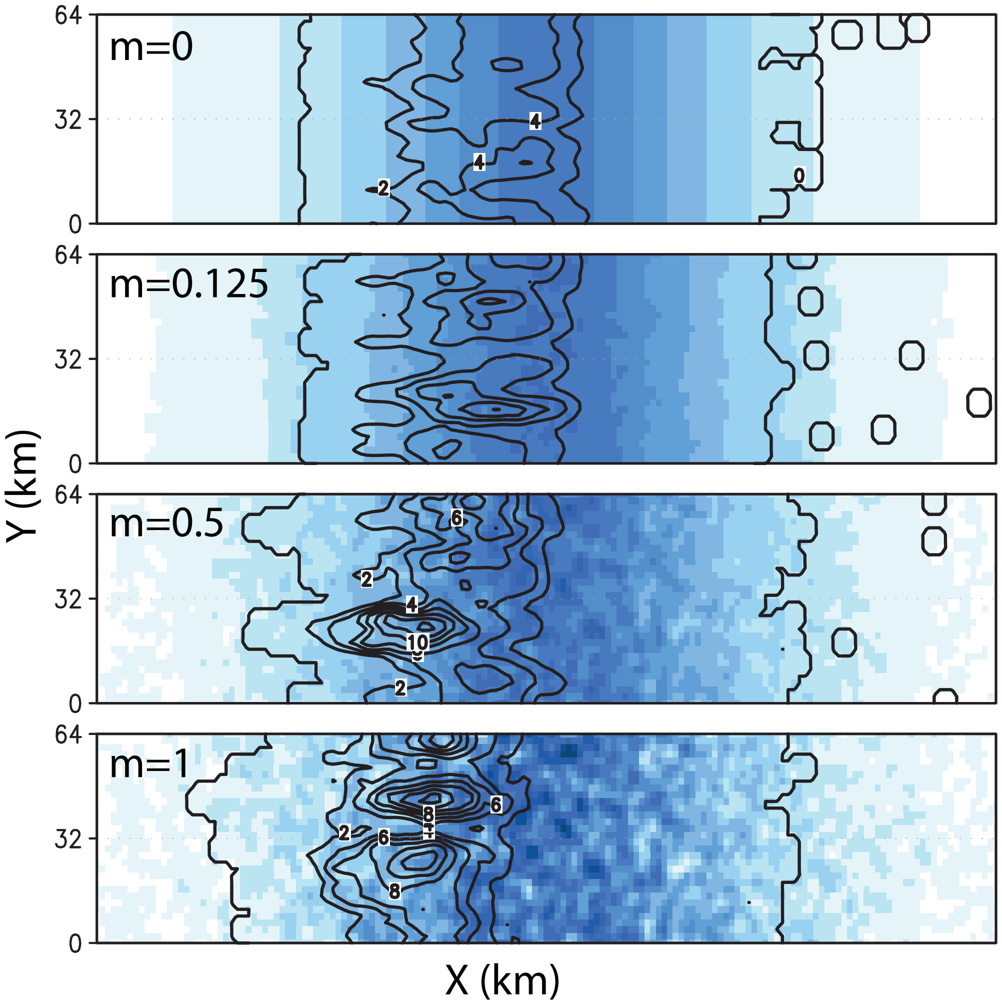
$$(u_b)_{i,1} = (w_b)_{i-1/2,1+1/2} = 0$$

Wu and Arakawa 2011

On the phase locking of precipitation over complex topography

- Precipitation seems to be localized as the topography becomes more complex


m: an index for the irregularity of the topography

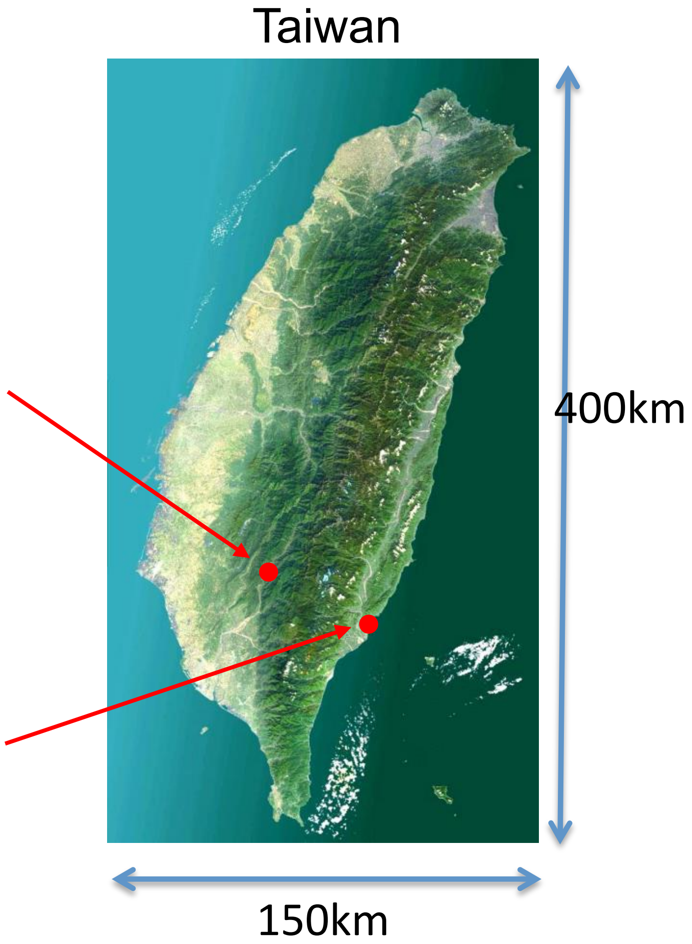

Contour: Precipitation (mm/hr)

Typhoon Morakot

- 2009 08/05-08/10
- Most devastating typhoon to hit Taiwan during the past 50 years. (total damage about NT$110 billion)

Shiao-Lin village buried by catastrophic mudslide, causing nearly 700 deaths

Collapse of a 6-story hotel in Taitung

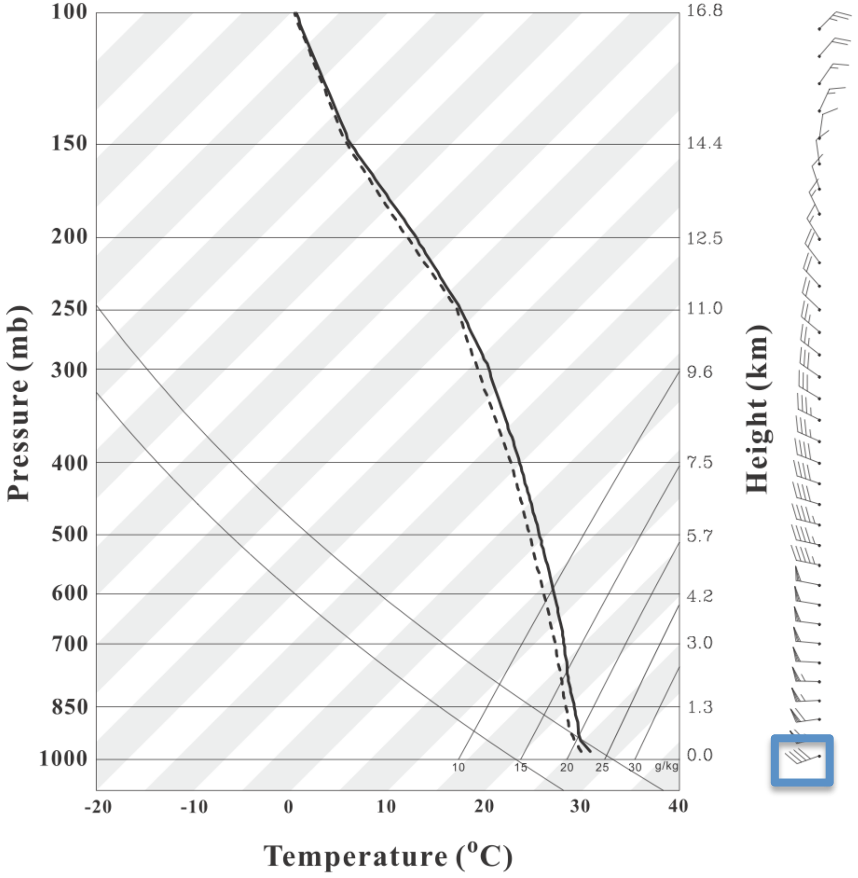


Curtsey from Professor Hung-Chi Kuo

Can VVM capture the precipitation pattern “without” the typhoon itself?

Initial soundings

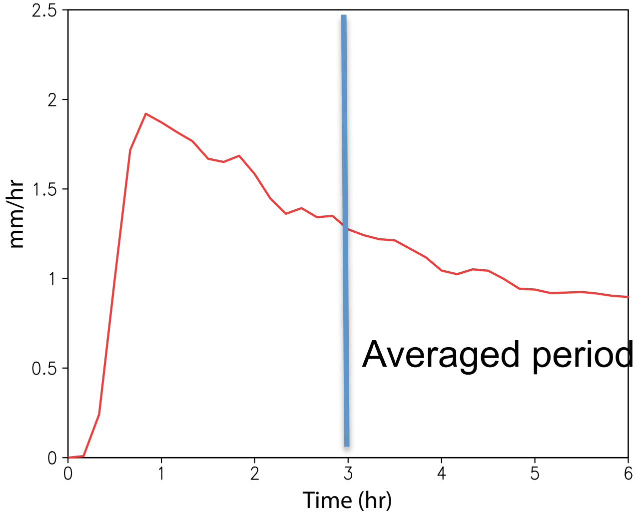
30 hours averaged profiles during typhoon Morakot



Adopted from Yu et al. 2013

Experiment setup :

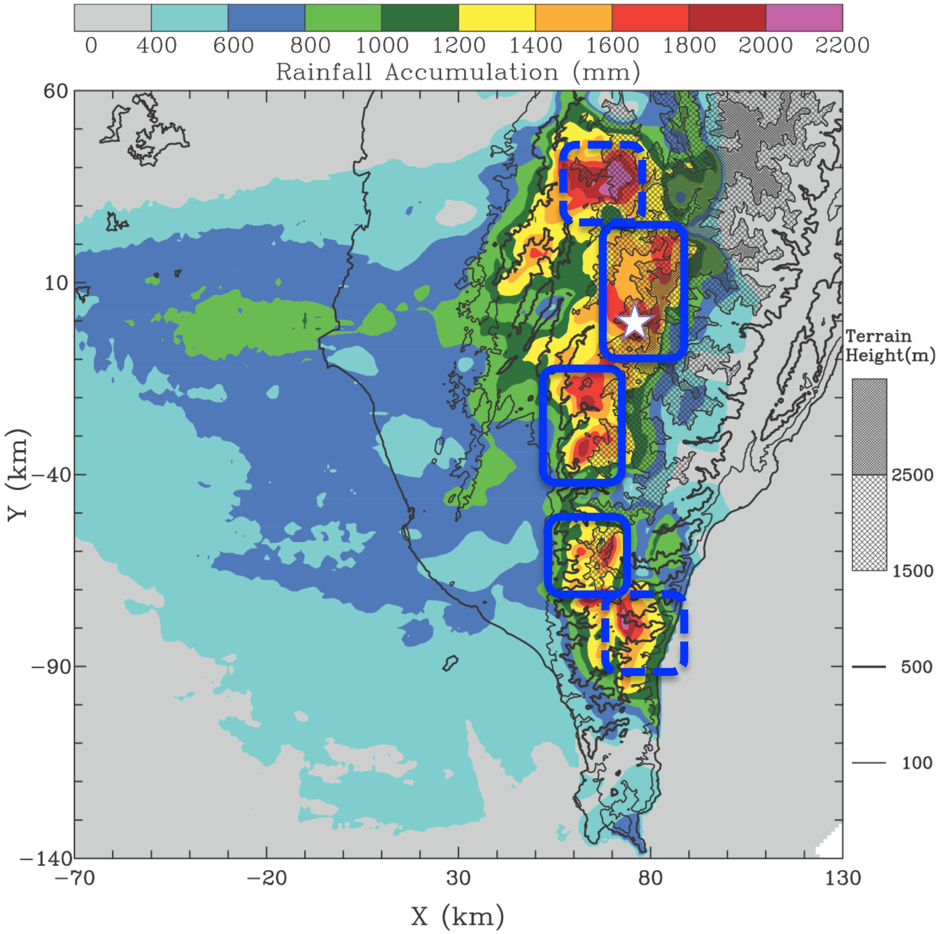
- Horizontal resolution: **1 km**
- Vertical resolution: **70 levels** with stretching grid with 50m near surface and 500m near model top
- Domain size: **1024x1024 km** with Taiwan in the center
- Wind field: **20 m/s south-westerly wind** over the domain
- Model is integrated for **6 hours** with averaged over the **last 3 hours** shown.
- Land surface is currently treated as water with fix ground wetness



Domain averaged precipitation (mm/hr)

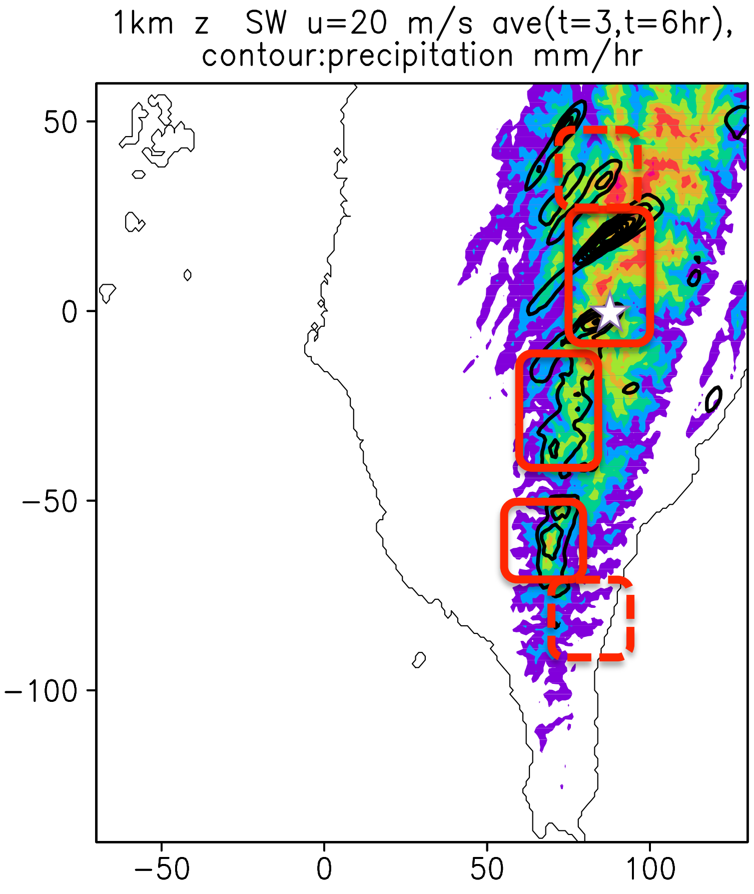
Results

Radar derived typhoon Morakot precipitation



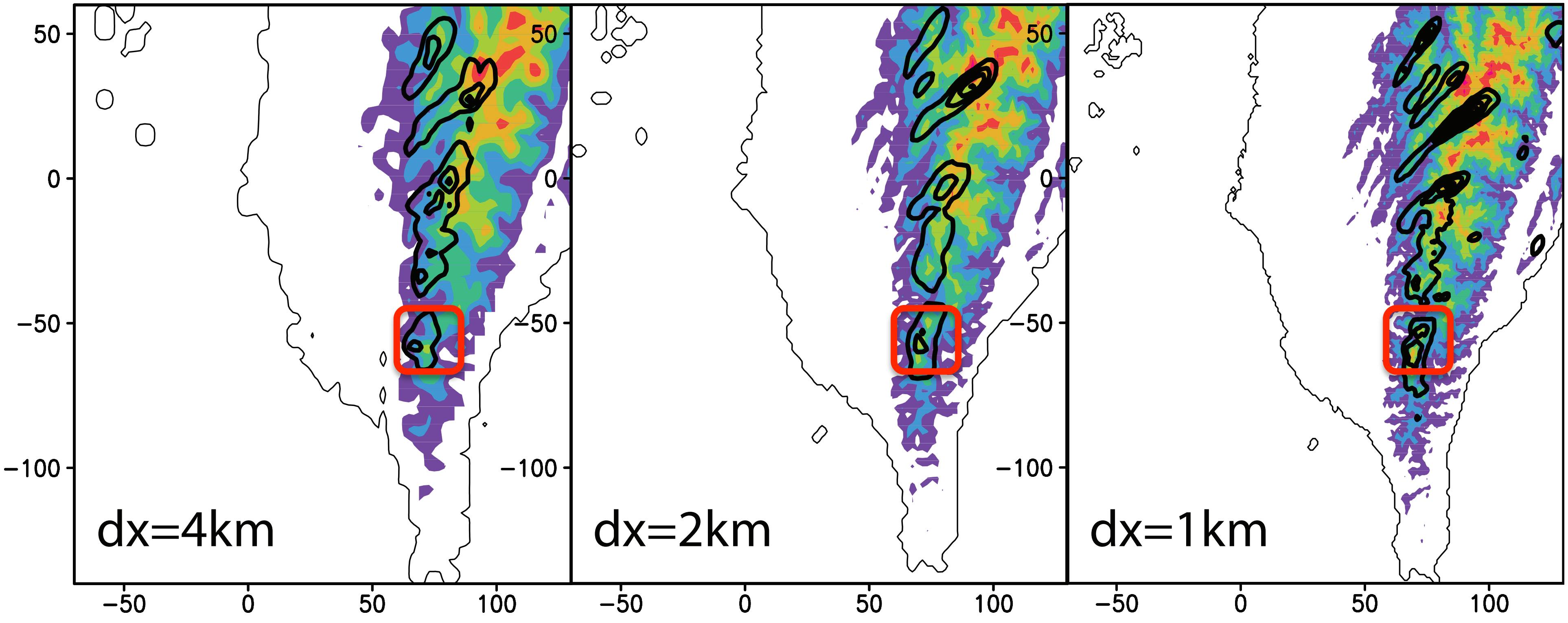
Adopted from Yu et al 2013

Idealized simulations with only South Westerly fl



Resolution dependency of orographic locking of precipitation

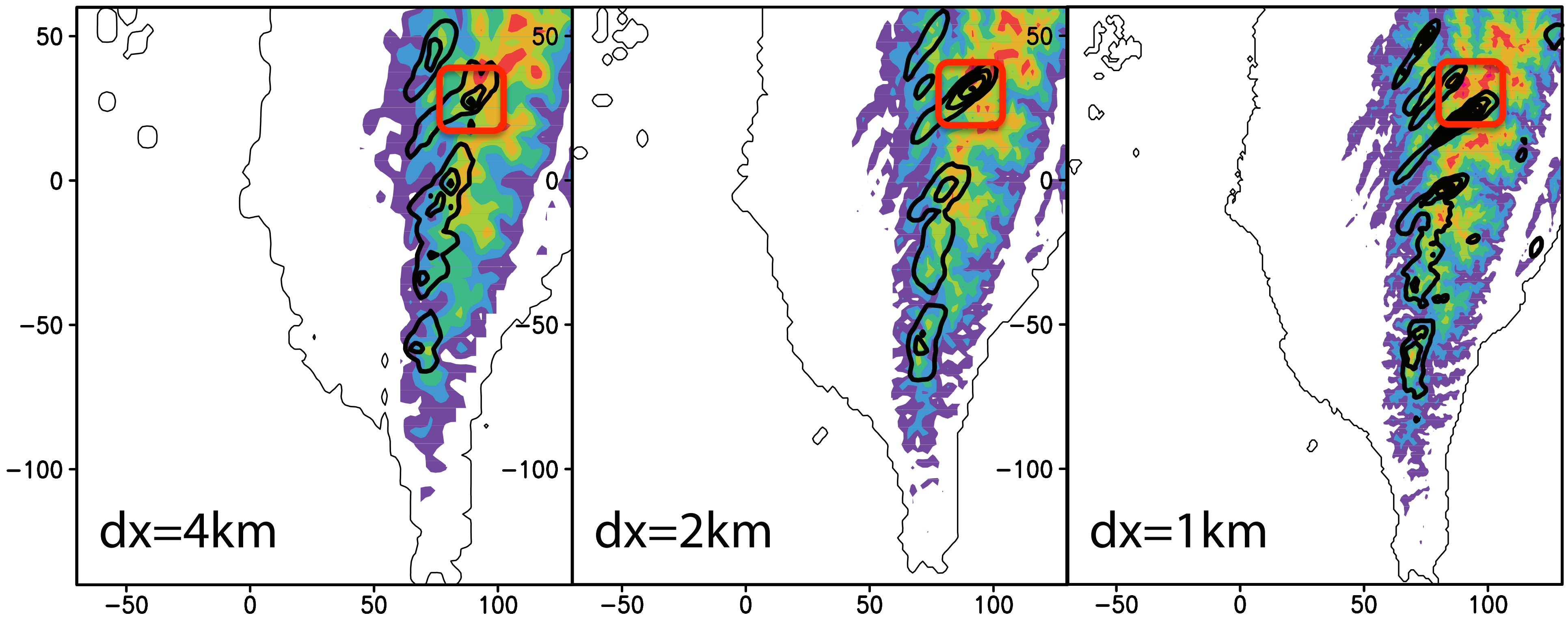
- Precipitation strength and pattern is similar among southern part of the mountain suggesting that the orographic lifting of precipitation dominates.



Contour: precipitation (10 mm/hr)

Resolution dependency of orographic locking of precipitation

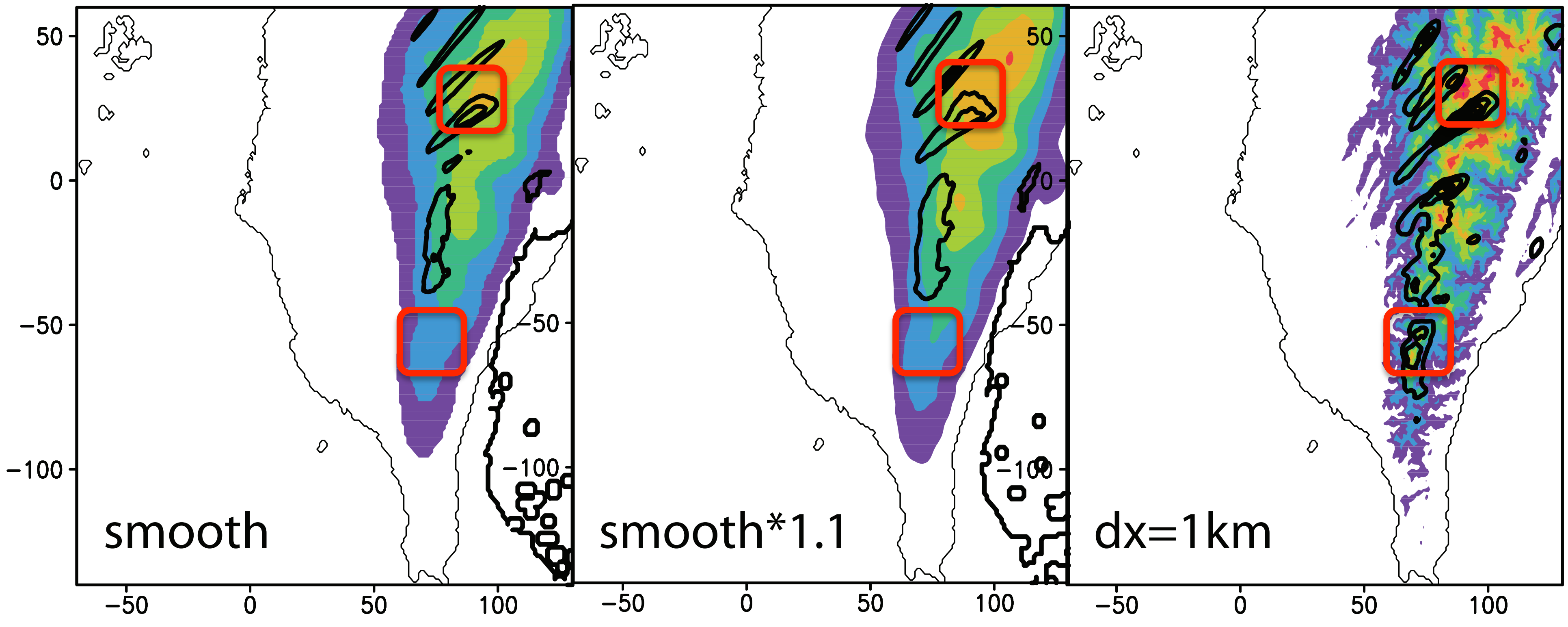
- Northern part of the mountain shows drastic difference in strength and location showing the importance of the effects of complex topography.



Contour: precipitation (10 mm/hr)

On the orographic complexity

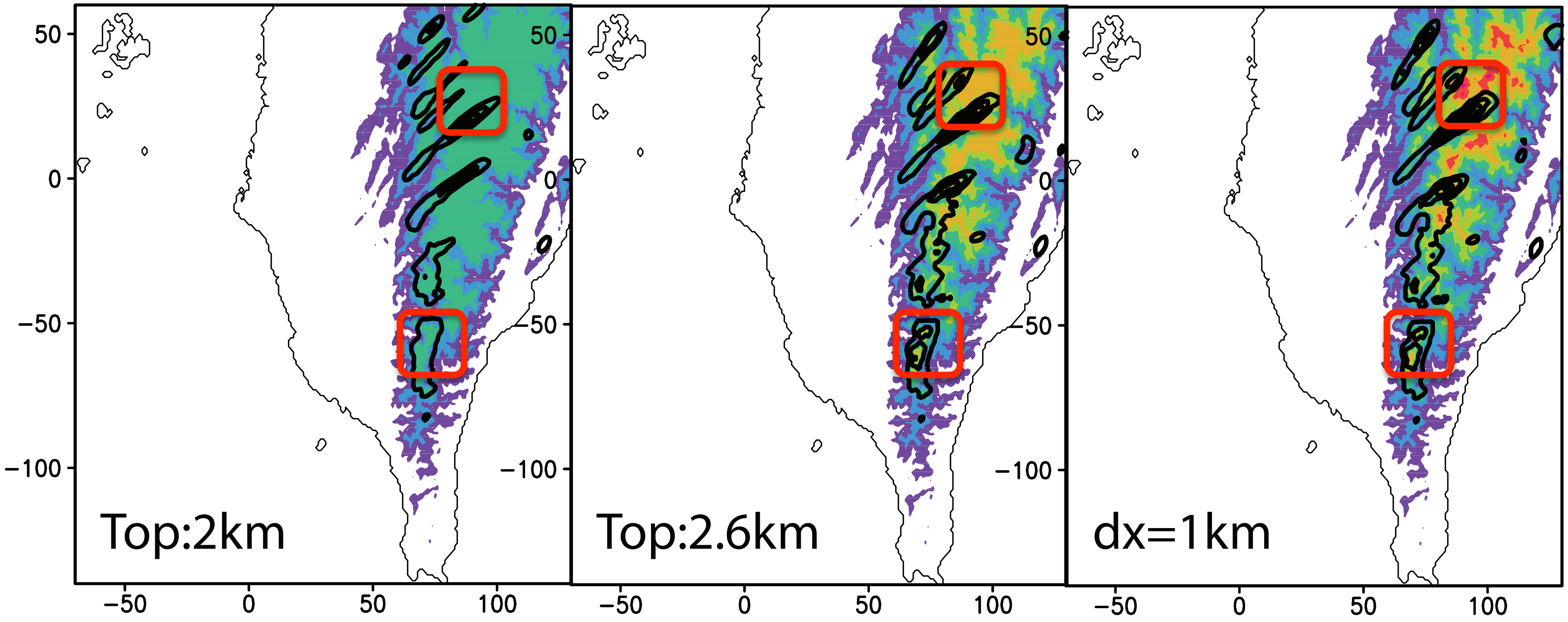
- Precipitation locking due to orography is greatly reduced in smooth topography.
- Increase mountain height only slightly enhances the precipitation.



Contour: precipitation (10 mm/hr)

On the effects of the valleys

- The precipitation locking is predetermined by the shapes of the valleys. The height of the mountain determines the maximum strength of precipitation.



Contour: precipitation (10 mm/hr)

Summary and future work

- Orographic locking of precipitation is very sensitive to the complexity of topography.
- Valley effects are more important than the mountain height in determining the precipitation pattern as long as the flow can pass the topography.
- Various strength and wind directions are tested to construct maps of precipitation produced only by the topography.

Preliminary results of a partial-grid block mountain in VVM

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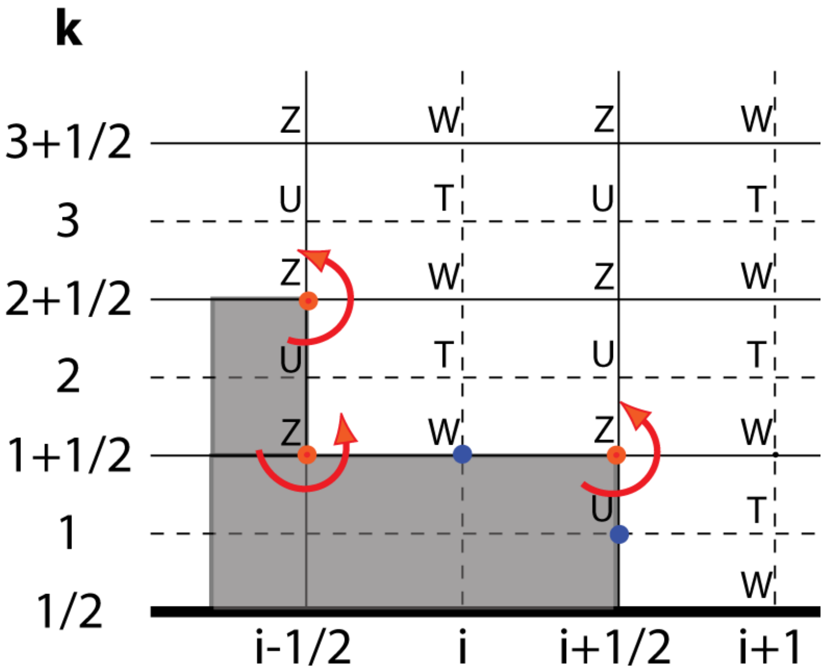
@CMMAP Jan 2014

The block mountain approach in VVM

DETERMINING THE VORTICITY AT THE CORNERS OF THE TOPOGRAPHY

- The strength of the vorticity at the corners is determined through vorticity definition.

$$\boxed{\eta_b = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \quad u_b = w_b = 0}$$



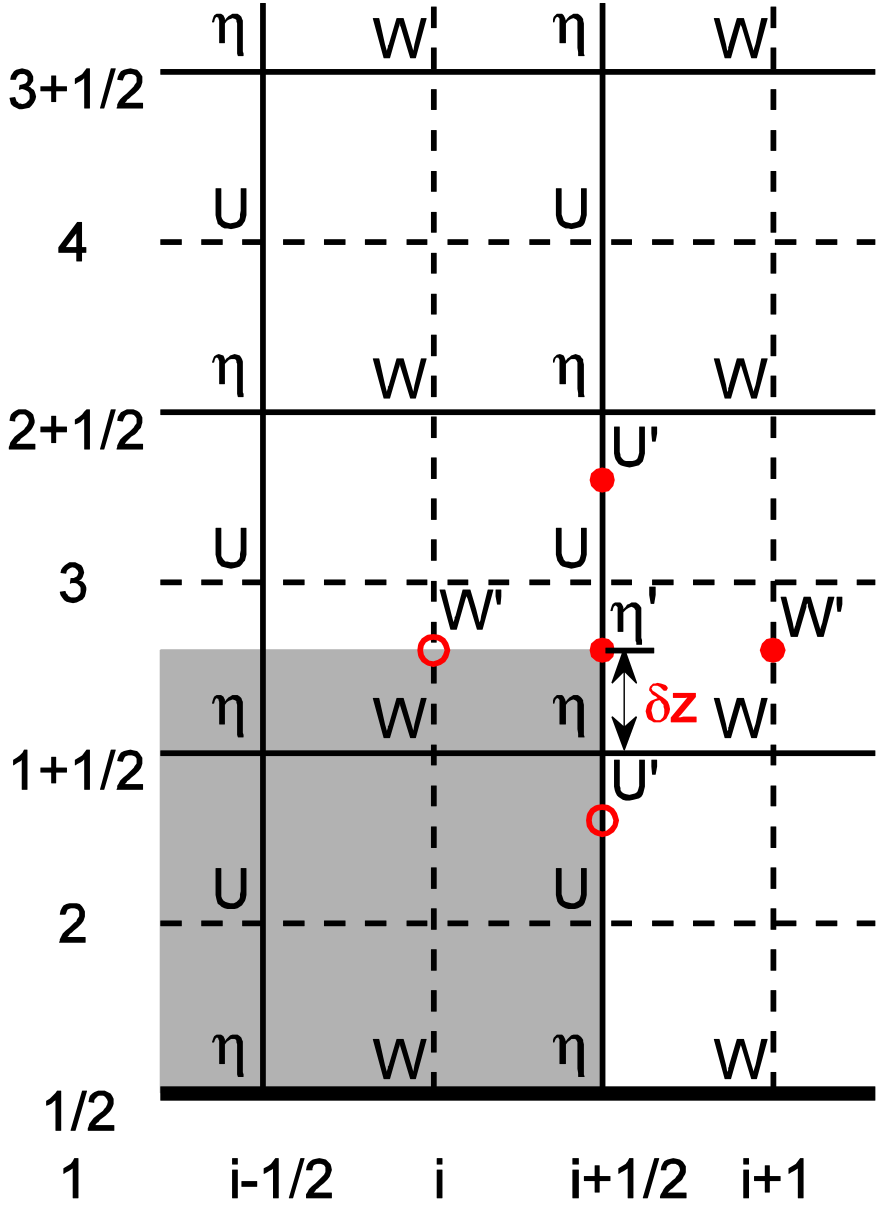
$$(\eta_b)_{i,1+1/2} =$$

$$\frac{u_{i,2} - \underline{(u_b)_{i,1}}}{\Delta z} - \frac{w_{i+1/2,1+1/2} - \underline{(w_b)_{i-1/2,1+1/2}}}{\Delta x}$$

$$(u_b)_{i,1} = (w_b)_{i-1/2,1+1/2} = 0$$

Wu and Arakawa 2011

Partial cell setup



The meridional vorticity

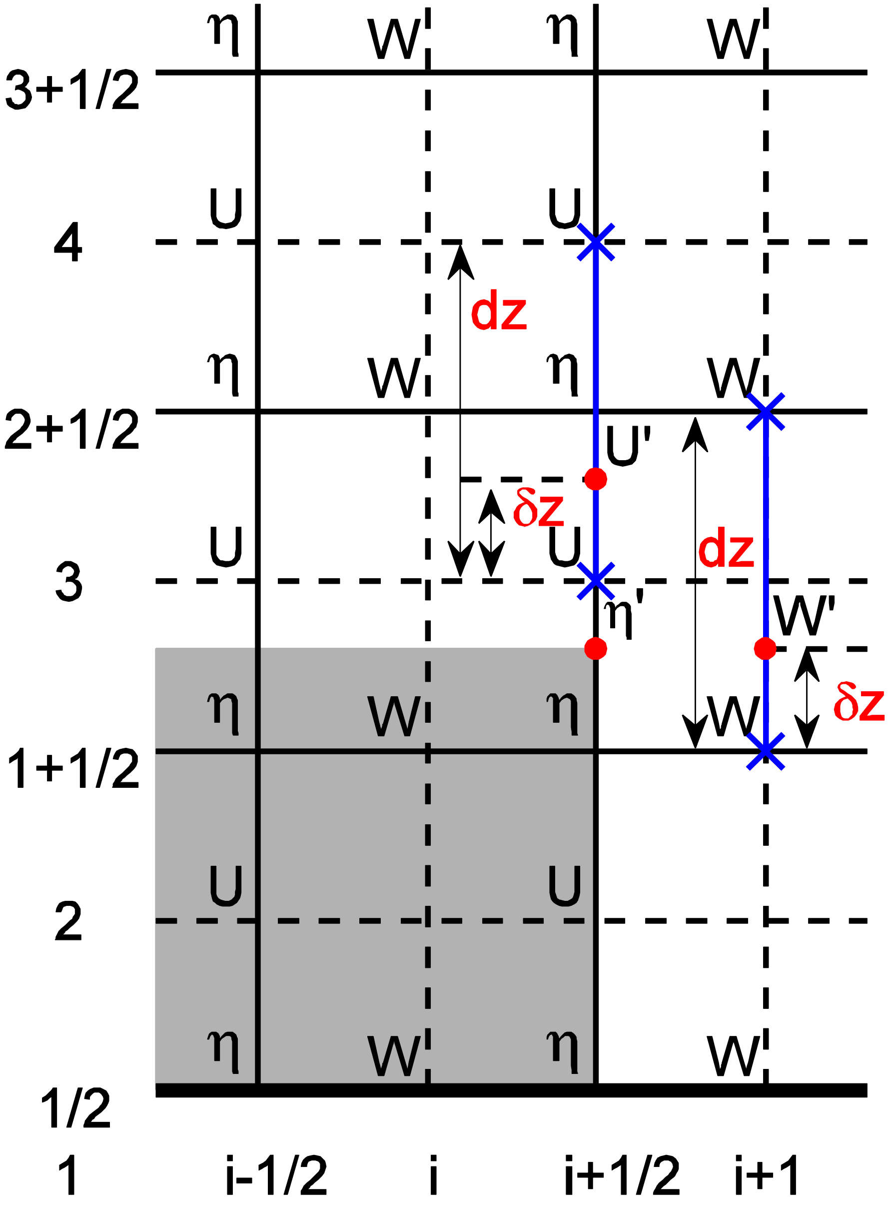
$$\eta'\Big|_{z+\delta z} = \frac{\partial W'}{\partial x} - \frac{\partial U'}{\partial z}$$

With δz above origin η point.

Where $W' = U' = 0$ at the physical boundary.

The U′ and W′ in the computational region apply linear interpolation.

Interpolation formula



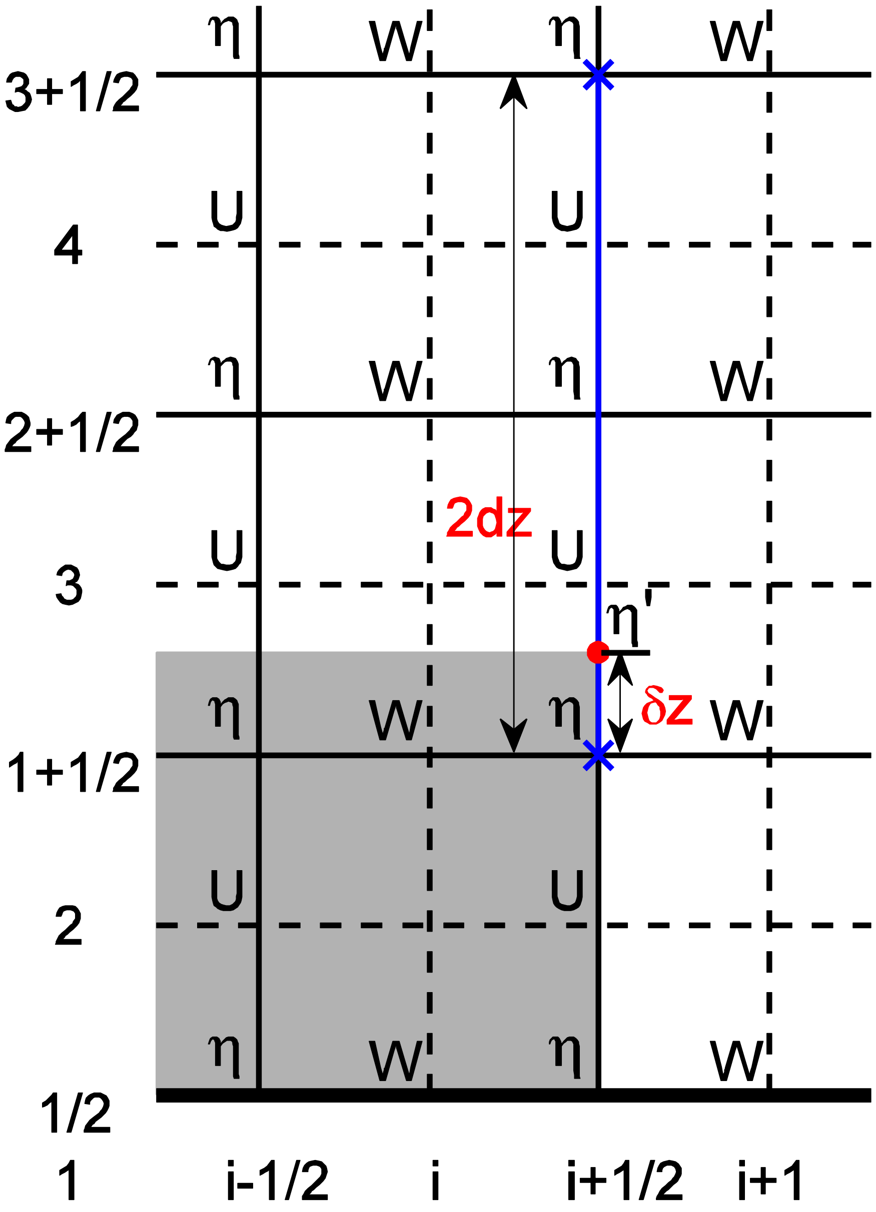
Let $\alpha = \delta z/dz$

$$U' = interp(U_3, U_4)$$
$$= (1-\alpha)U_3 + \alpha U_4$$

$$W' = interp\left(W_{1+1/2}, W_{2+1/2}\right)$$
$$= (1-\alpha)W_{1+1/2} + \alpha W_{2+1/2}$$

$$\eta' = \frac{W'}{dx} - \frac{U'}{dz}$$

Extrapolation to grid point



Apply $\eta_{3+1/2}$ and η' to extrapolate the $\eta_{1+1/2}$

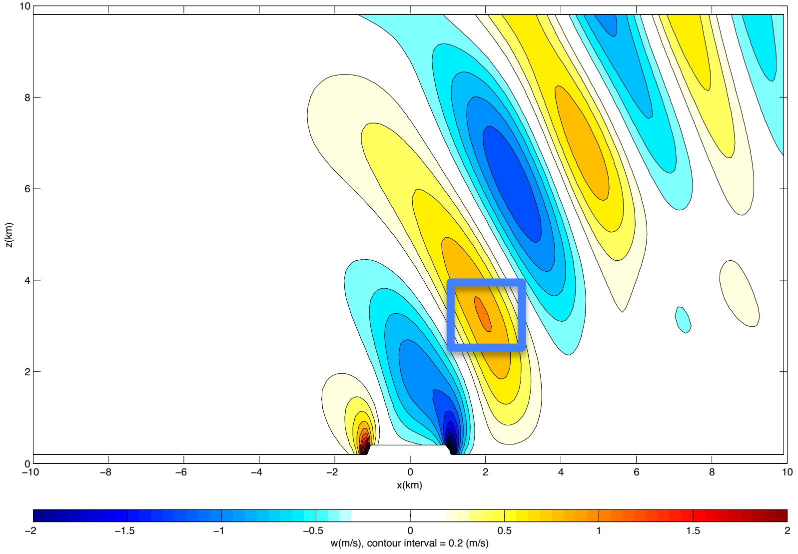
Let $\beta = \delta z/2dz$

$$\eta' = (1-\beta)\eta_{1+1/2} + \beta\eta_{3+1/2}$$

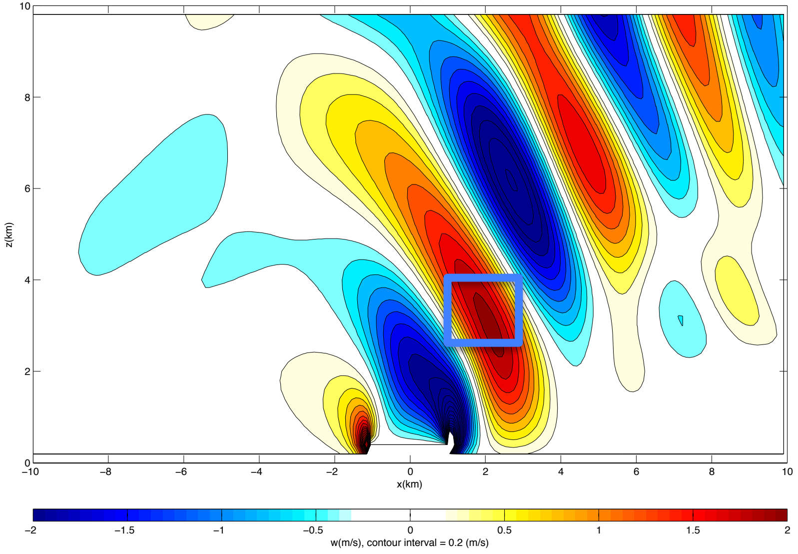
$$\eta_{1+1/2} = \eta' - \beta\eta_{3+1/2}/(1-\beta)$$

Gravity wave results from "full cell" block mountain

- The strength of the mountain wave depends linearly on the mountain height.



Vertical velocity with **100m** mountain



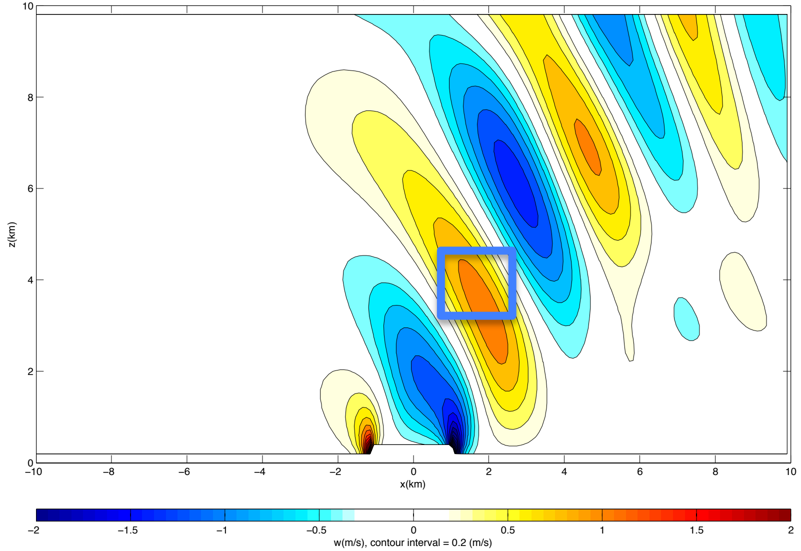
Vertical velocity with **200m** mountain

Control experiment: dx=dy=dz=100m, U=10 m/s

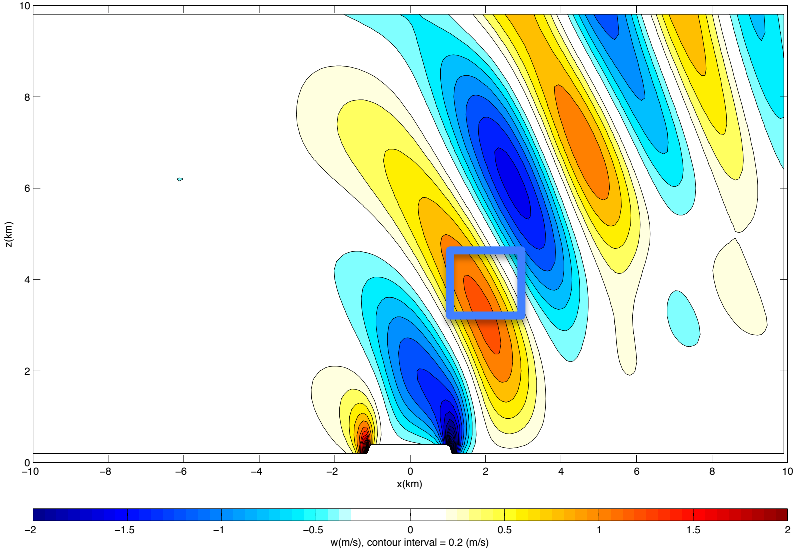
Block mountain height: 100m (1dz) and 200m (2dz)
Mountain width: 1 km.

Gravity wave results from “partial cell” block mountain

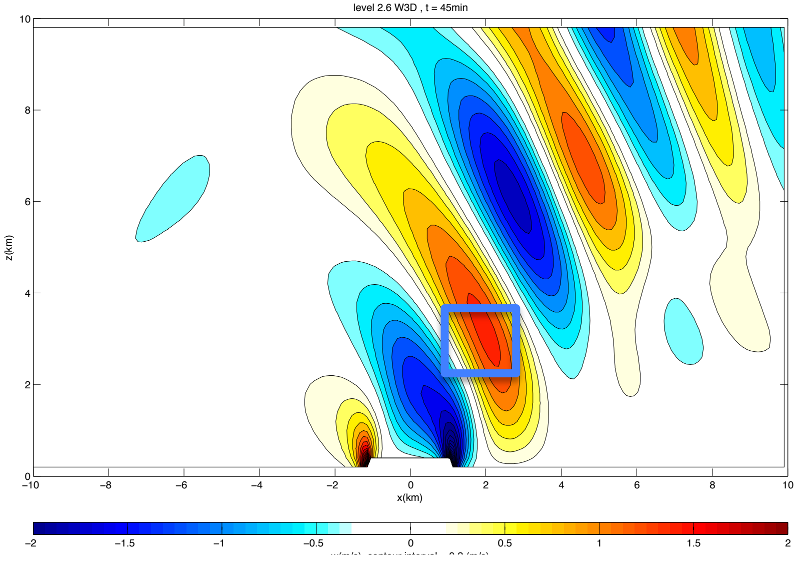
Vertical velocity with **100m** mountain



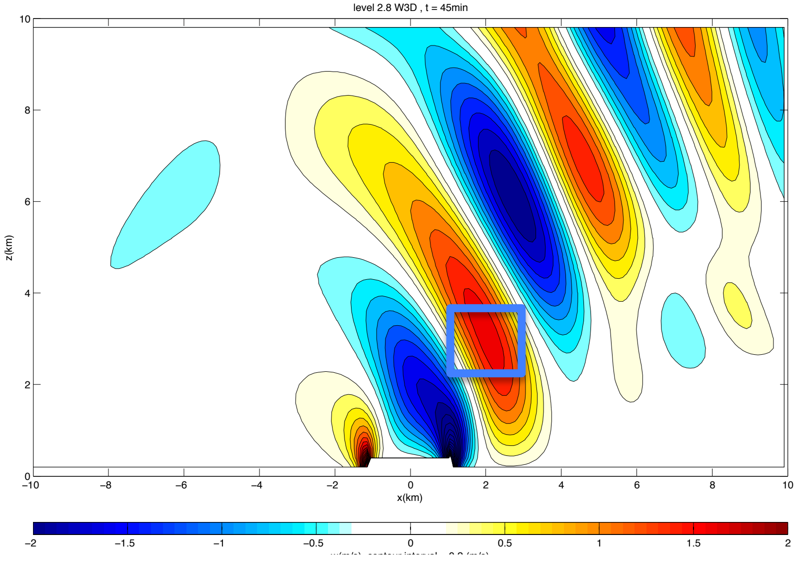
Vertical velocity with **120m** mountain



Vertical velocity with **140m** mountain



Vertical velocity with **180m** mountain



Summary and future work

- Preliminary results suggest that the simple interpolation/ extrapolation works for the partial grid mountains in the gravity wave simulations.

- There are still problems with lower boundary when the mountains are within the first grid.

- A BICG solver for the w-equation is implemented to try to solve this problem by changing coefficients in the lower boundary.