

凡那比颱風(2010)與米塔颱風(2019)之次環流  
結構：理想化軸對稱颱風模式結果與WRF模式  
模擬結果之比較與探討

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# 科學問題

- 理想化軸對稱颱風模式可以描述多少WRF模式的結果？驗證凡那比颱風(2010)個案。
- 變更斜壓性與潛熱加熱強度、分布，會如何影響颱風的徑向風(radial wind)、垂直速度(vertical velocity)、溫度趨勢(temperature tendency)?

# 理想化軸對稱颶風模式

- (Schubert et. al., 2007)
- 假設：**颶風軸對稱**
  - 大氣無黏滯力
  - 密度隨高度變化
  - 梯度風平衡
  - f-plane
- 以圓柱座標表示：
  - $(r, \theta, z) \rightarrow$  (徑, 切, 垂直)
  - 風速： $(u, v, w)$
  - 原點：颶風中心、高度為0

控制方程：

$$\left\{ \begin{array}{l} \left(f + \frac{v}{r}\right) v = \frac{\partial \phi}{\partial r} \\ \frac{Dv}{Dt} + \left(f + \frac{v}{r}\right) u = 0 \\ \frac{\partial \phi}{\partial z} = \frac{g}{T_0} T \\ \frac{\partial(rv)}{r\partial r} + \frac{\partial w}{\partial z} - \frac{w}{H} = 0 \\ c_p \frac{DT}{Dt} + \frac{RT}{H} w = Q \\ z = H \log\left(\frac{P_0}{P}\right), H = \frac{RT_0}{g} \end{array} \right.$$

# Sawyer-Eliassen Equation

$$\frac{\partial}{\partial r} \left( A \frac{\partial(r\psi)}{r\partial r} + B \frac{\partial\psi}{\partial z} \right) + \frac{\partial}{\partial z} \left( B \frac{\partial(r\psi)}{r\partial r} + C \frac{\partial\psi}{\partial z} \right) = \frac{g}{c_p T_0} \frac{\partial Q}{\partial r}$$

$$A = e^{\frac{z}{H}} \frac{g}{T_0} \left( \frac{\partial T}{\partial z} + \frac{\kappa T}{H} \right) \quad B = -e^{\frac{z}{H}} \frac{g}{T_0} \frac{\partial T}{\partial r} = -e^{\frac{z}{H}} \left( f + \frac{2v}{r} \right) \frac{\partial v}{\partial z}$$

$$C = e^{\frac{z}{H}} \left( f + \frac{2v}{r} \right) \left( f + \frac{\partial(r\psi)}{r\partial r} \right)$$

B.C. : radial       $\psi = 0$  when  $r = 0$   
                           $r\psi \rightarrow 0$  when  $r \rightarrow \infty$

vertical       $\psi = 0$  when  $z = 0$   
                           $\psi = 0$  when  $z = \text{tropopause}$

$$u = -e^{\frac{z}{H}} \frac{\partial\psi}{\partial z}$$

$$w = e^{\frac{z}{H}} \frac{\partial(r\psi)}{r\partial r}$$

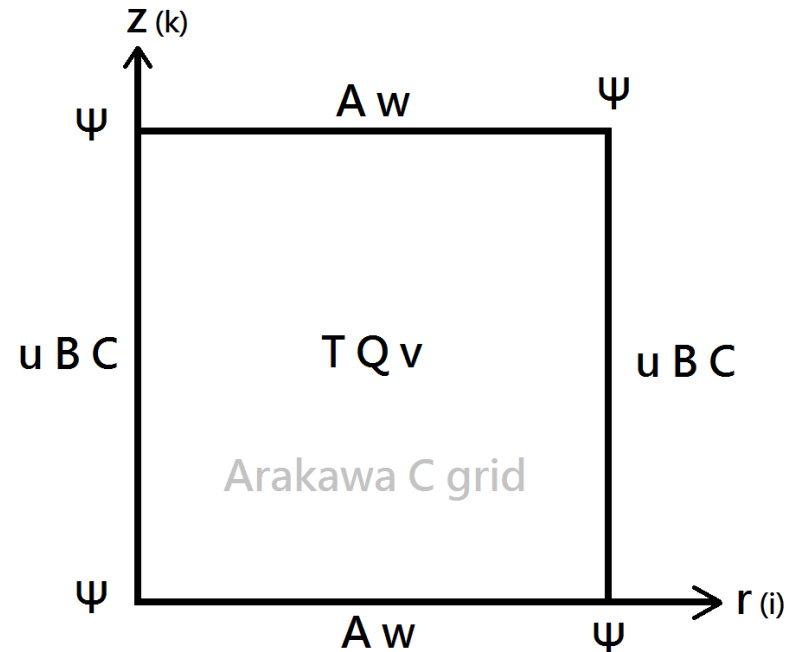
$$\frac{\partial}{\partial r} \left( A \frac{\partial(r\psi)}{r\partial r} + B \frac{\partial\psi}{\partial z} \right) + \frac{\partial}{\partial z} \left( B \frac{\partial(r\psi)}{r\partial r} + C \frac{\partial\psi}{\partial z} \right) = \frac{g}{c_p T_0} \frac{\partial Q}{\partial r}$$

- Sawyer-Eliassen Equation 寫為差分方程 (中差分)
- 網格配置: Arakawa C grid
- 解 $\psi$ 可得:

$$u = -e^{\frac{z}{H}} \frac{\partial\psi}{\partial z}$$

$$w = e^{\frac{z}{H}} \frac{\partial(r\psi)}{r\partial r}$$

$$\frac{\partial T}{\partial t} = \frac{Q}{C_p} - A \frac{g}{T_0} \frac{\partial(r\psi)}{r\partial r} - B \frac{g}{T_0} \frac{\partial\psi}{\partial z}$$



# 研究方法 - WRF模式設定

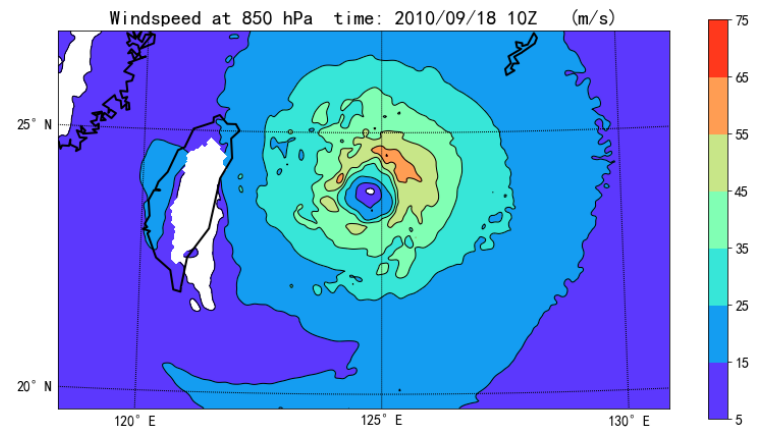
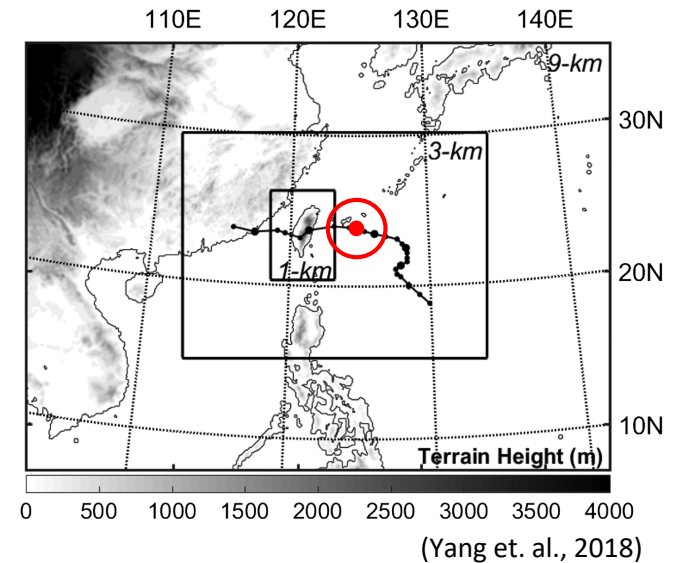
- 使用(Yang et. al., 2018)凡那比颱風(2010)個案WRF設定。

- WRF ARW version 3.9
- Time: 2010-09-18 00 UTC~  
2010-09-20 06 UTC

Domain Size: 9, 3, 1 km

- Number of levels: 55 eta level

- 使用 3-km domain  
2010-09-18 10 UTC



# 研究方法 - 理想化模式設定

- 徑方向      1 ~ 650 km      網格大小 1 km  
  垂直方向    40 ~ 960 hPa      網格大小 20 hPa

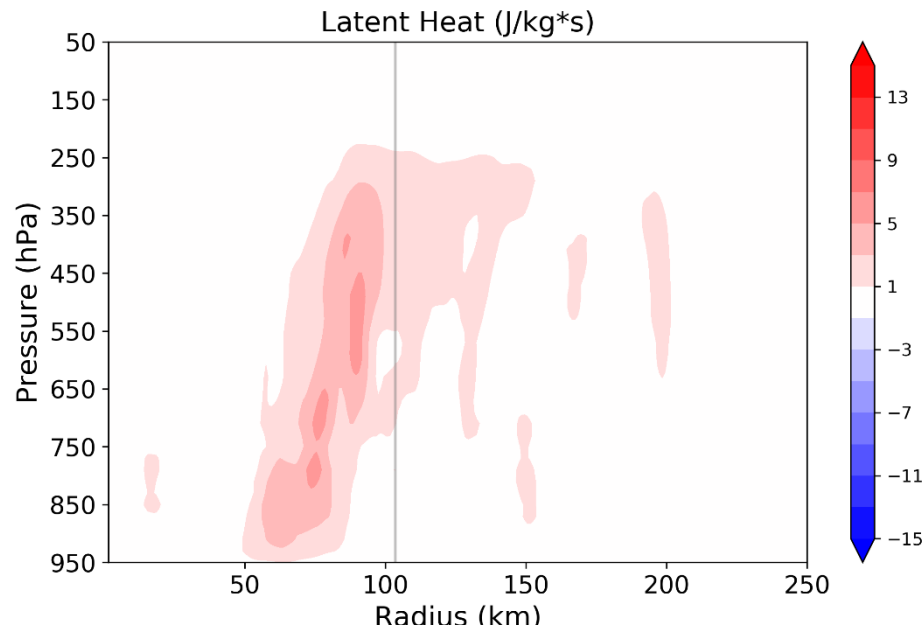
## 改變斜壓性分布

實驗 參數	正壓	斜壓
A	由WRF結果計算	
B	0	由WRF結果計算
C	由WRF結果計算	
$\frac{\partial Q}{\partial r}$	由WRF結果計算	

# 研究方法 - 理想化模式設定

## 改變潛熱分布

- 主雨帶實驗
  - 依潛熱強度，距中心100公里處分為眼牆與主雨帶
  - 完整(對照組)、主雨帶移除





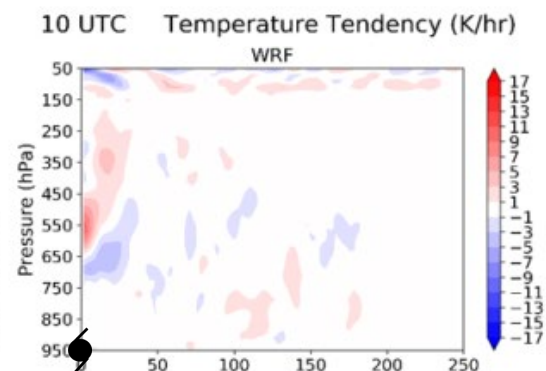
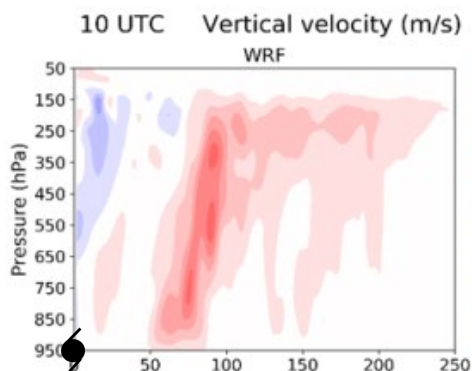
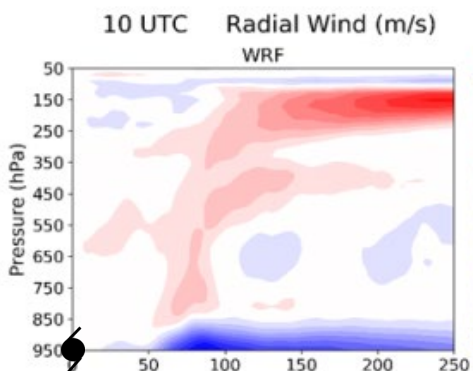
# 結果 - 理想化 vs. WRF

徑向風  $u$

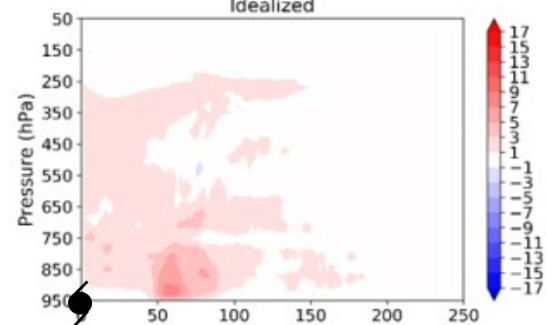
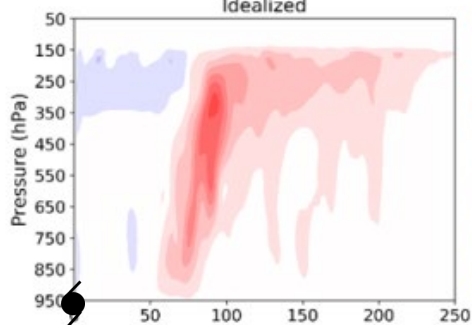
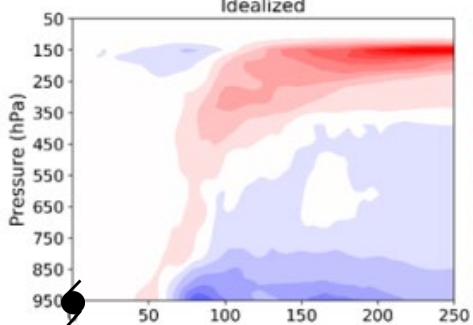
垂直速度  $w$

溫度趨勢  $\frac{\partial T}{\partial t}$

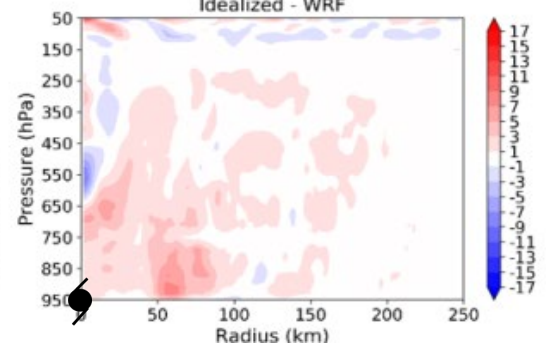
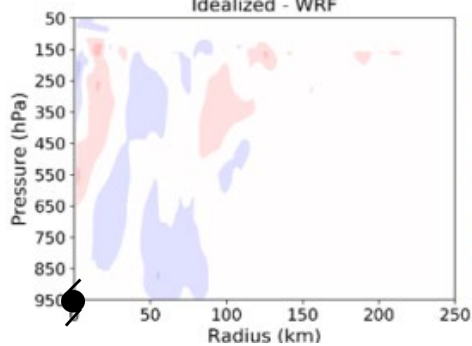
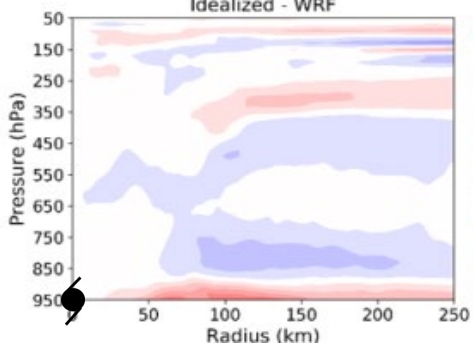
WRF



理想化



理想化  
- WRF

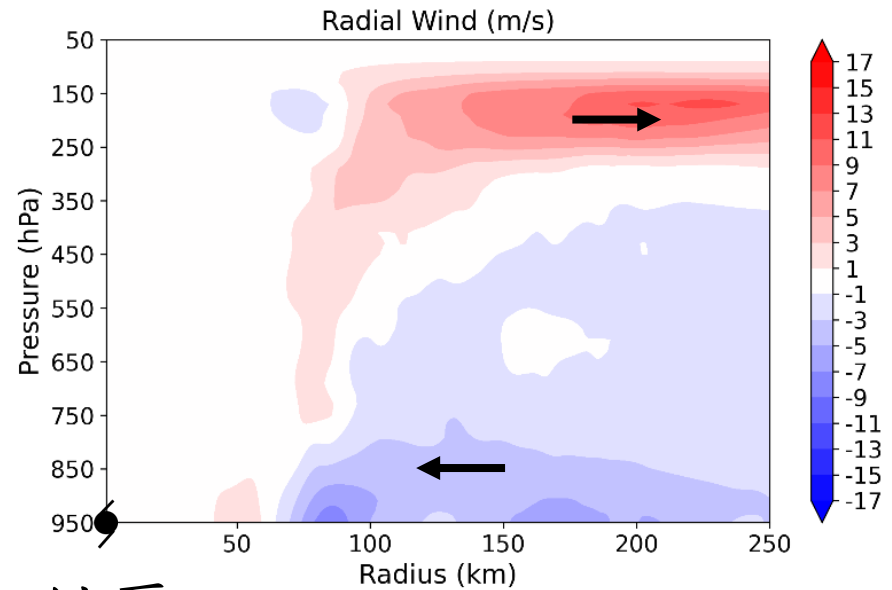


# 改變斜壓性 徑向風 $u$

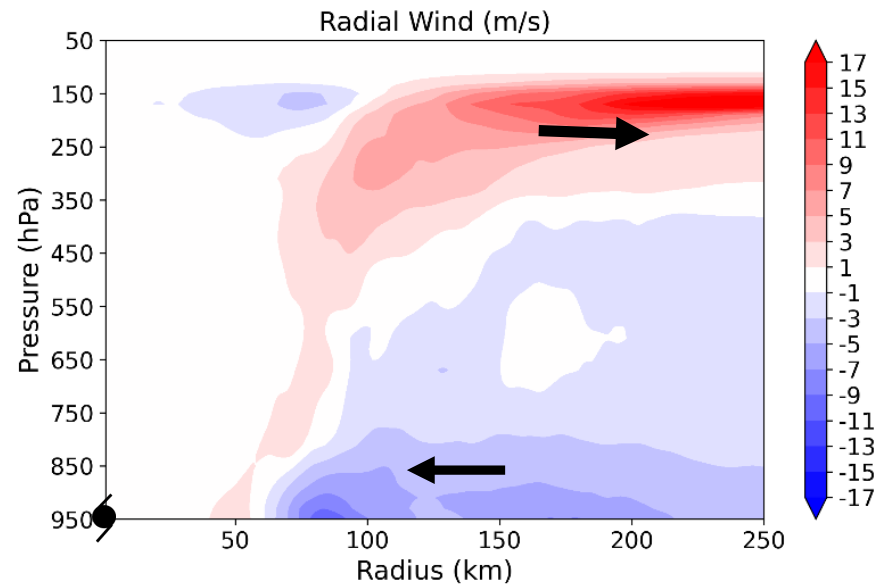
斜壓性

- 中心高溫、外圍低溫
- 高層中心壓力較高
- 出流增強

正壓



斜壓



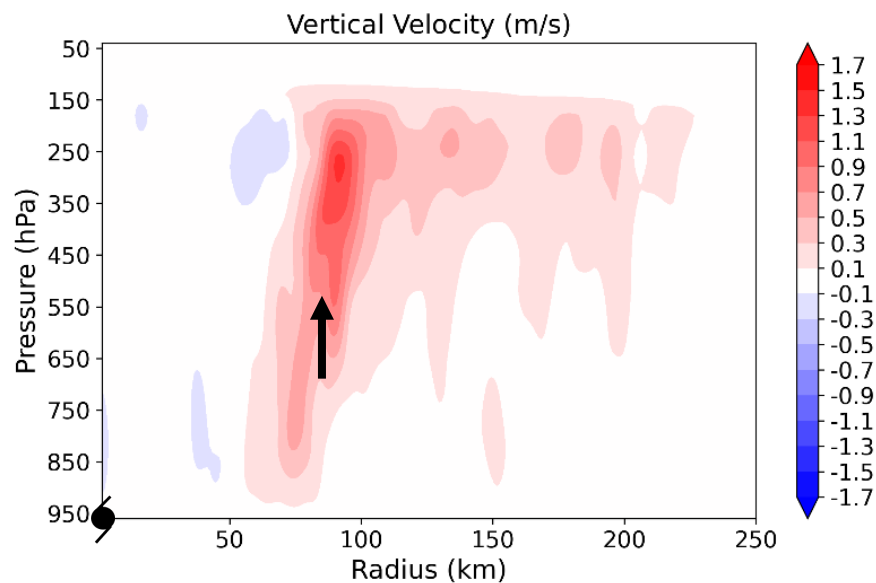
# 改變斜壓性 垂直速度 $w$

斜壓性

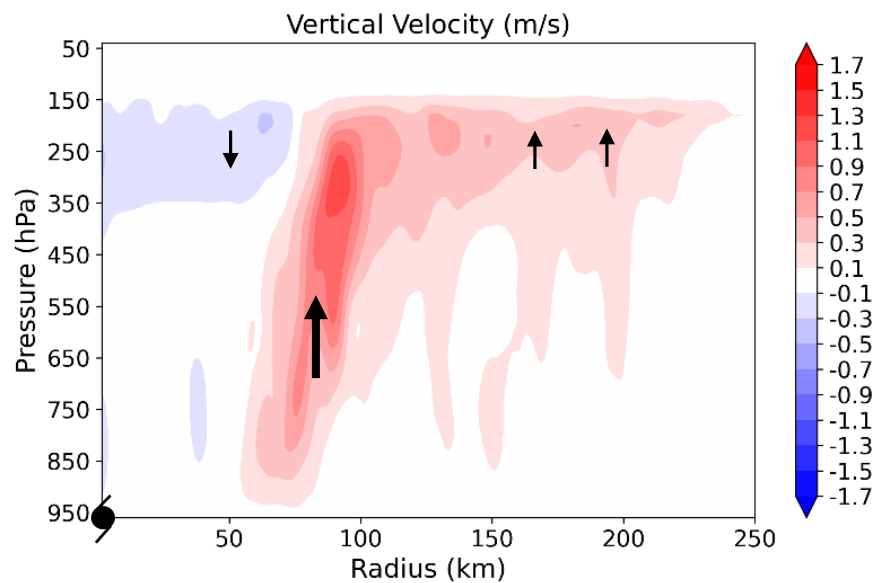
→ 出流增強

→ 上升運動增強

## 正壓



## 斜壓



# 改變斜壓性 溫度趨勢 $\frac{\partial T}{\partial t}$

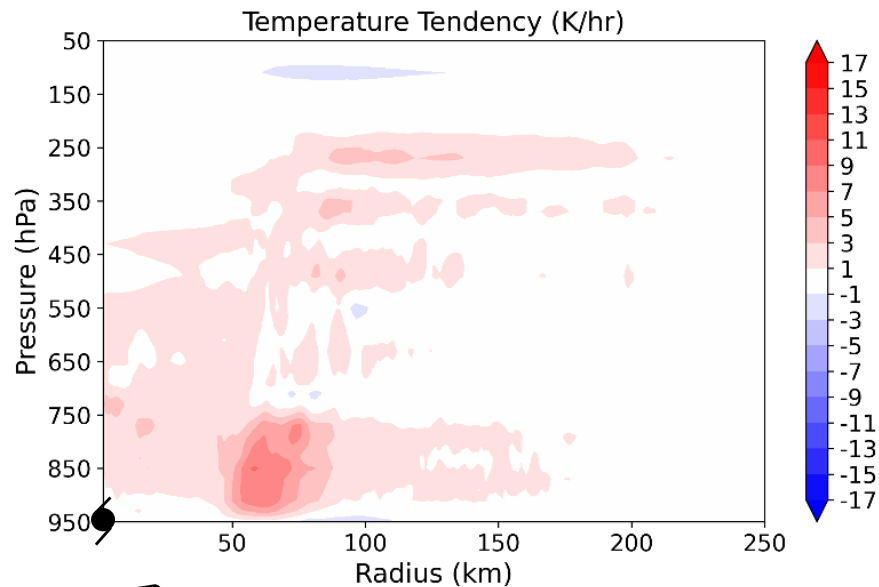
斜壓性

→ 中心高溫、外圍低溫

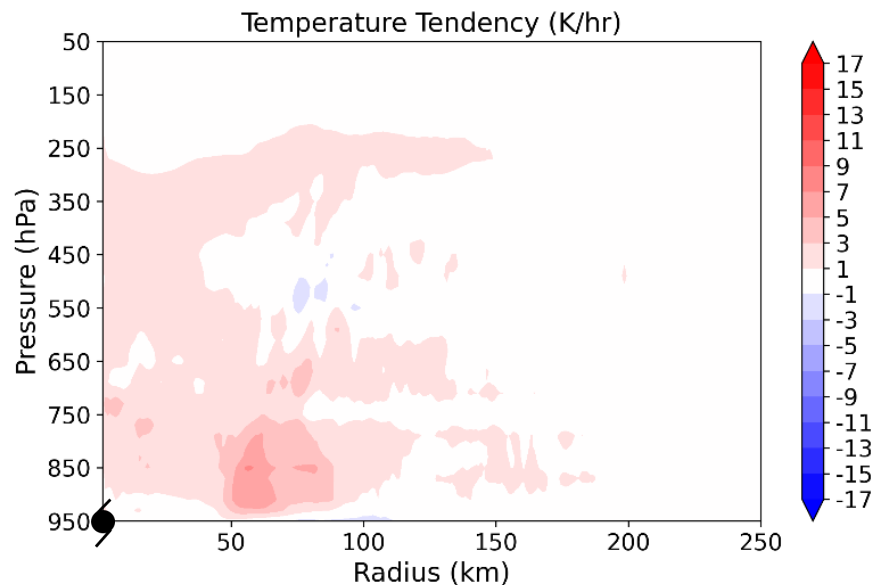
+ 低層入流

→ 冷平流抵消升溫

正壓



斜壓



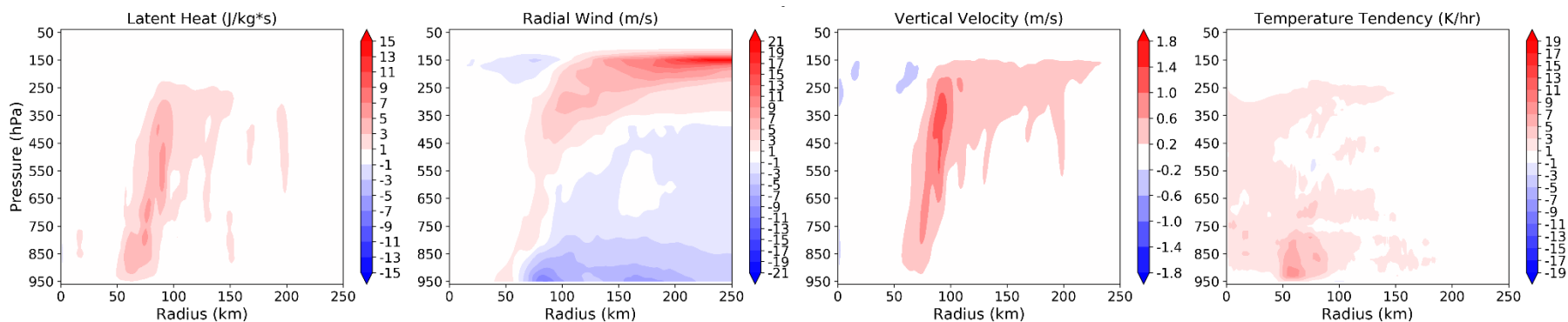
# 改變潛熱分布

完整

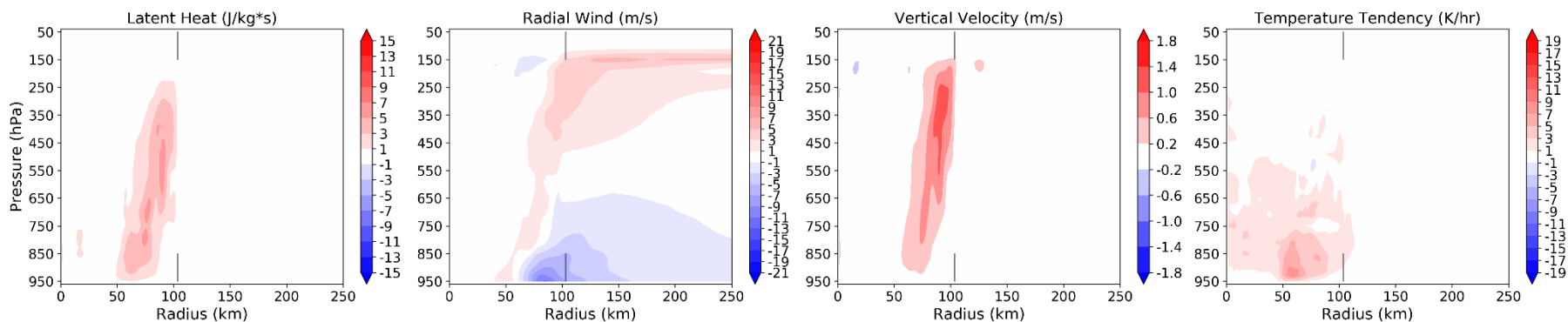
徑向風

垂直速度

溫度趨勢



主雨帶移除



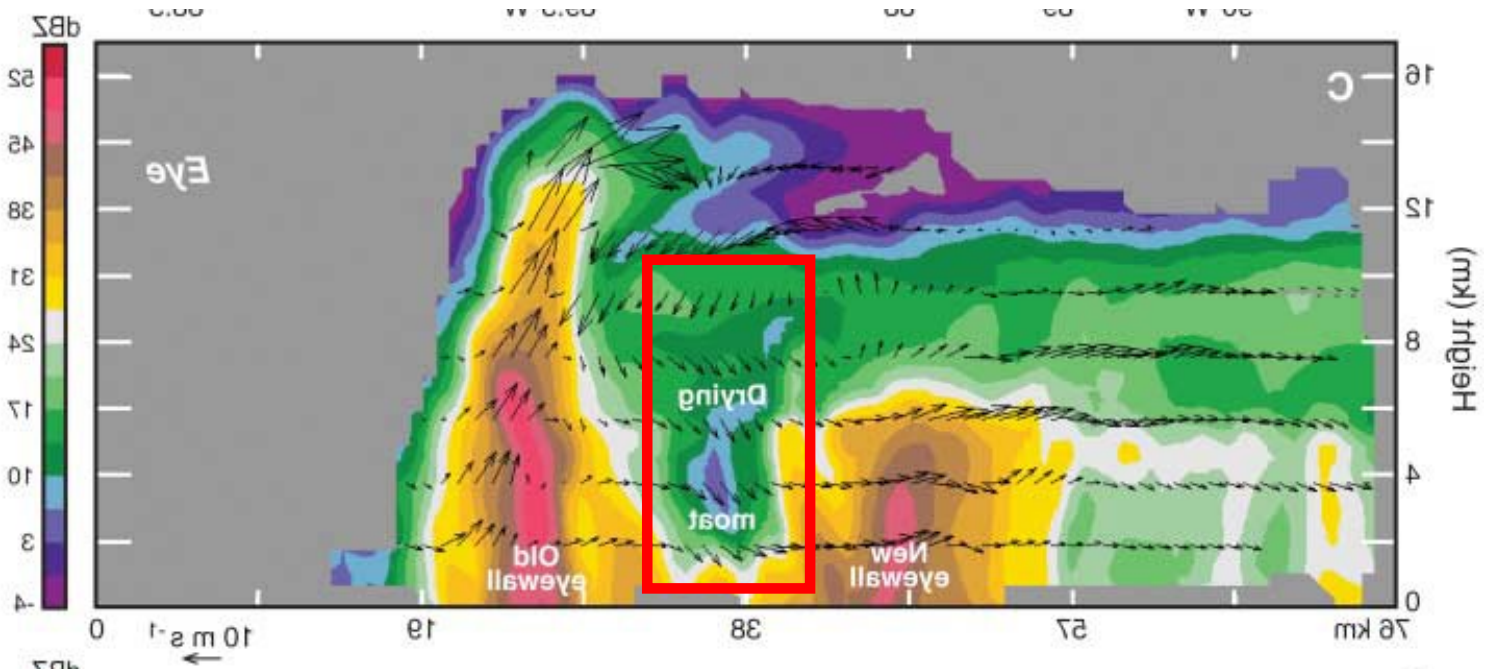
# 整理

- 因理想化模式未考慮高層雲頂輻射冷卻及亂流、低層摩擦力，理想化模式與WRF模式於高層、低層差異較大。
- 斜壓性存在，使次環流較明顯。低層入流與高層出流增強、上升氣流增強增廣、眼內下沉增強、低層溫度趨勢減弱。
- 主雨帶潛熱存在，使次環流較強、較完整。暖心結構較廣，中層入流存在。

# Future Work

## 雙眼牆實驗

Hurricane Rita (2005)



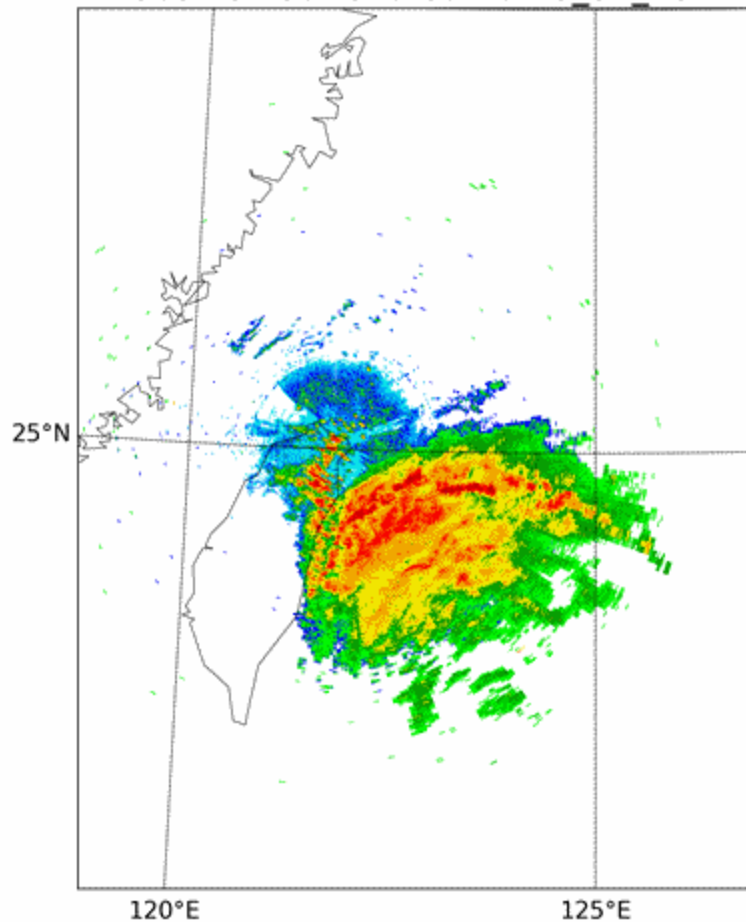
(Houze et. al., 2007)



9/29 20:00 UTC

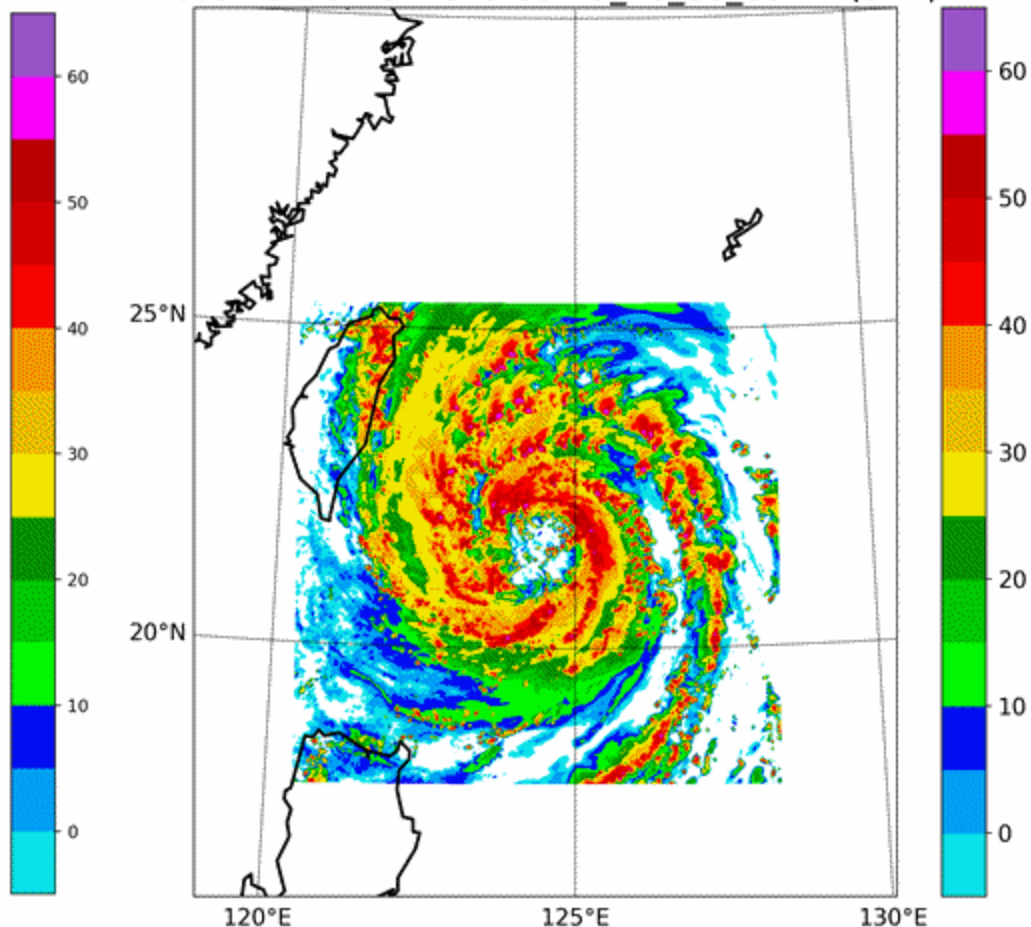
米塔颱風(2019)

Radar CV at 2019-09-29 20\_02\_10Z



五分山

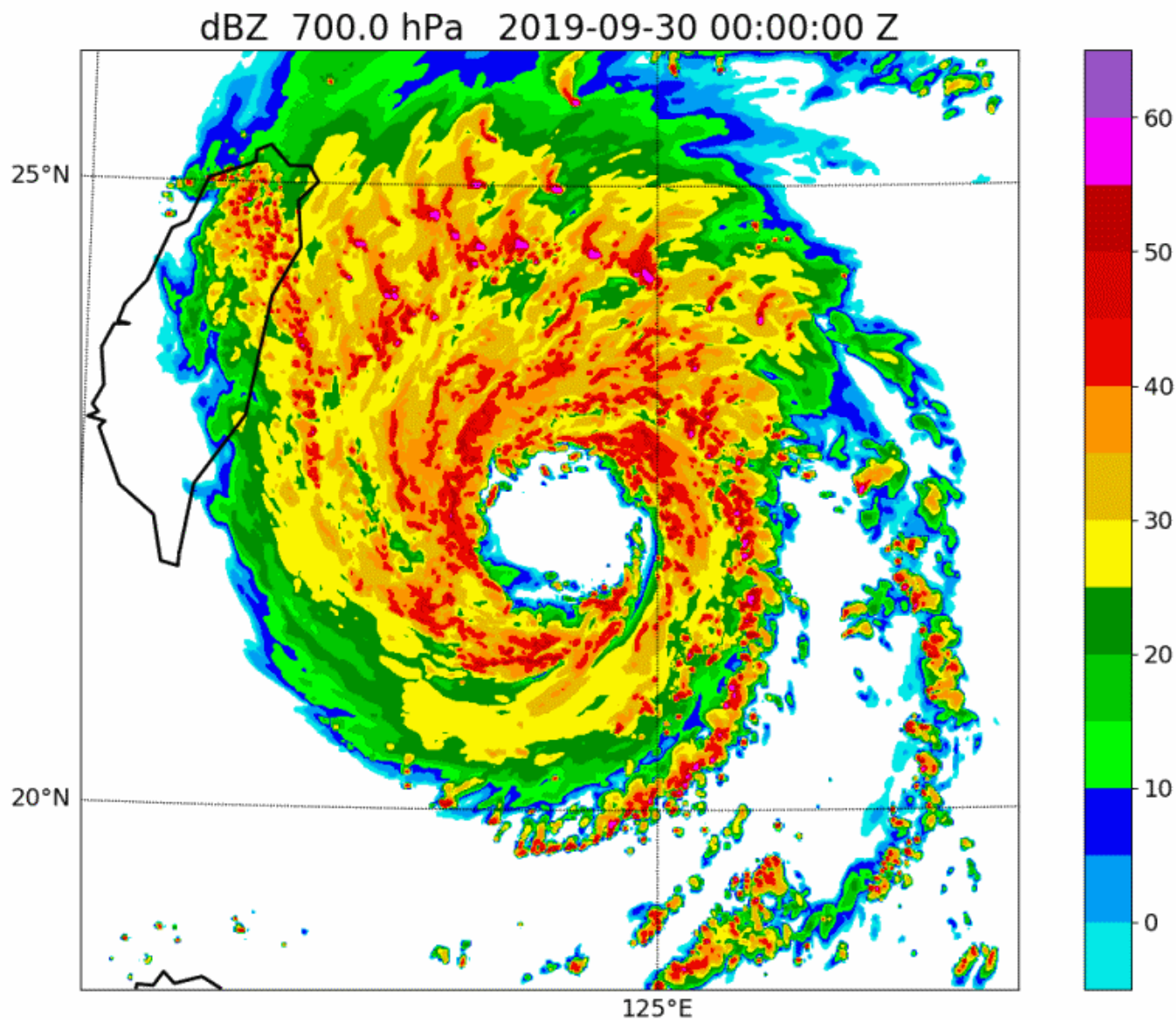
Radar CV time: 2019-09-29 20\_00\_00 Z (dBZ)



WRF



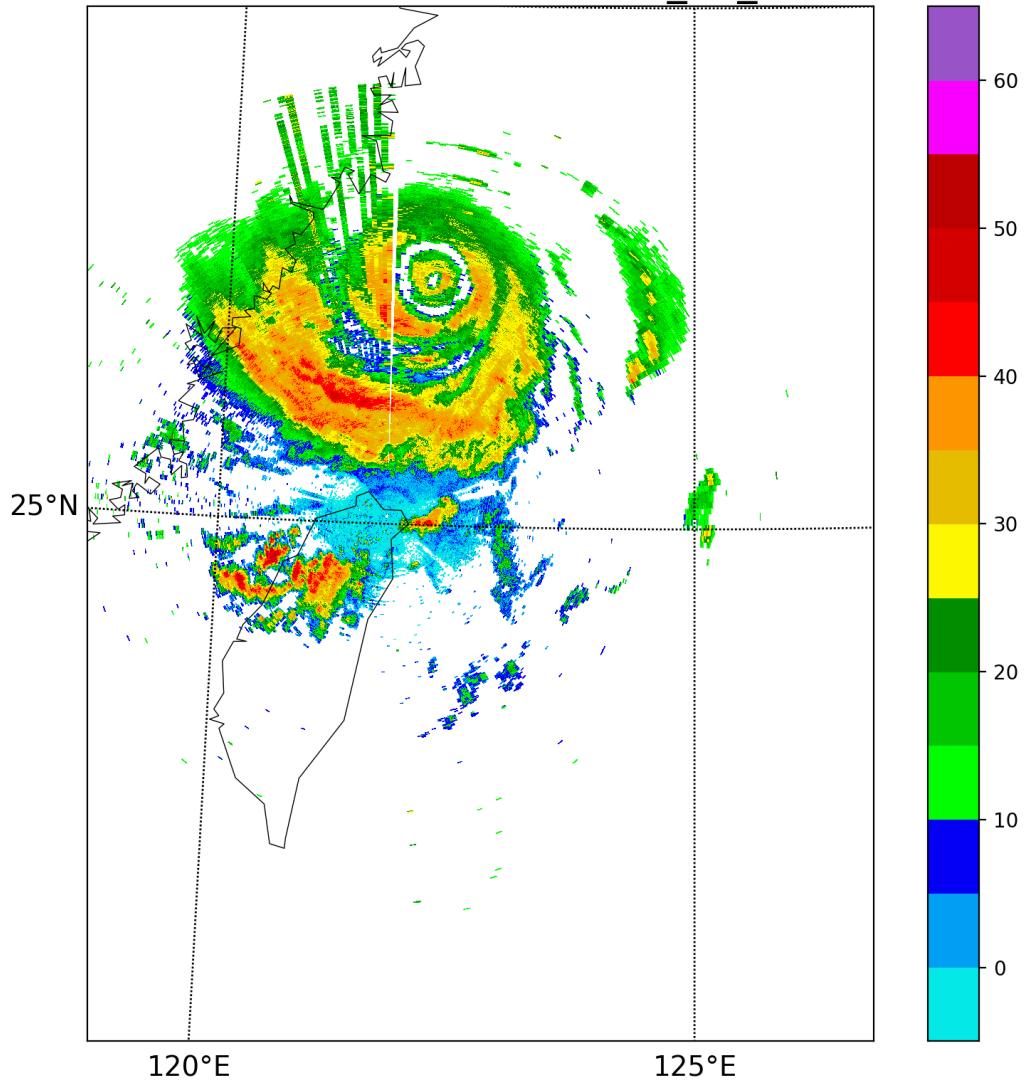
# WRF Simulation 1 km grid size 5 minutes output



8/9 10:32 UTC

利奇馬颱風(2019)

Radar CV at 2019-08-09 10\_32\_55Z



The End

# 參考文獻

- Houze, R. A., Jr., S. S. Chen, B. F. Smull, W.-C. Lee, and M. M. Bell, 2007: Hurricane intensity and eyewall replacement. *Science*, **315**, 1235-1239.
- Schubert, W. H., C. M. Rozoff, J. L. Vigh, B. D. McNoldy, and J. P. Kossin, 2007: On the distribution of subsidence in the hurricane eye. *Q. J. R. Meteorol. Soc.*, **133**, 595-605.
- Yang, M.-J., Y.-C. Wu, and Y. -C. Liou, 2018: The Study of Inland Eyewall Reformation of Typhoon Fanapi (2010) Using Numerical Experiments and Vorticity Budget Analysis. *J. Geophys. Res. Atmos.*, **123**, 9604-9623.