A NUMERICAL STUDY OF THE TORNADO-LIKE VORTEX EVENT OVER OAHU, HAWAII ON 8 JUNE 2003

CHIH-YING CHEN[1], YI-LENG CHEN[2], FENG HSIAO[3], CHUAN-YAO LIN[1*]

1. RCEC, ACADEMIA SINICA, TAIWAN
2. DEPARTMENT OF ATMOS, UNIVERSITY OF HAWAII, USA
3. NOAA CENTER IN ATMOSPHERIC SCIENCES AND METEOROLOGY, HOWARD UNIVERSITY, USA

文獻回顧

夏威夷群島降雨特徵:

- **信風**：夏季出現機率高達 **93%**（SCHROEDER, 1993）
- **降雨影響因子**：夏季受 **地形效應與局地效應**影響（GIAMBELLUCA ET AL., 1986; 2013）
- **既有研究**：多集中於 **冷季（11－4月）**強降雨事件（SCHROEDER, 1977; TU & CHEN, 2011; ZHANG ET AL., 2005; MURPHY & BUSINGER, 2011）
- **最新資料**：2000－2015 年暖季（5－10月），**歐胡島平均每年 0.9 次白天強降雨事件** → 目前尚未研究

[Xiao et. al., MWR, 2020]

哪些環境條件有利於此類強降雨事件的發生？
是哪些動力或熱力過程觸發了對流的形成？

June 8 2003 歐胡島中部強降雨事件

- 天氣型態 (SYNOPTIC CONDITIONS)
  - REX 阻塞＋夏威夷西側高空槽
  - 深厚濕層＋條件不穩定大氣
  - 低層弱風＋西北側冷鋒/切變線

- 模式結果 (Model Results)
  - 雷達反射率：模擬與觀測相符
  - 陸面加熱 → 混合層加深至 LCL
  - 海風/陸風循環 → 暖濕海洋氣流進入歐胡島中部

[Xiao et. al., MWR, 2020]

Honolulu County

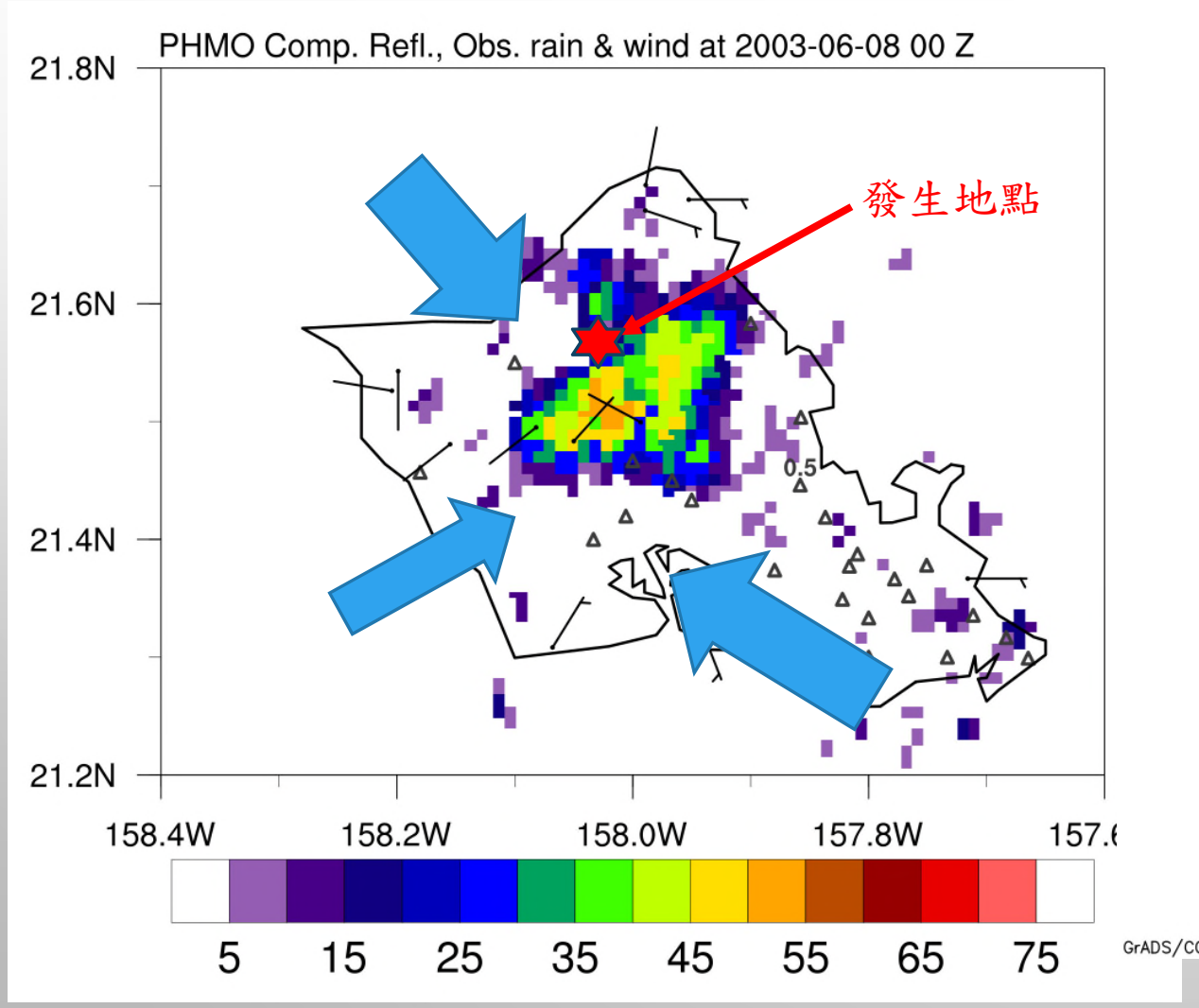
3 NE Mililani Town	**07**	**1501HST** **1510HST**	**0**	**10**	**0**	**0**	**Tornado (F0)**

A weak tornado was seen by a National Weather Service spotter over the Koolau mountain range above Mililani, in central Oahu. The feature began to move southward toward Pearl City and dissipated before being able to do any property damage or cause any injuries.

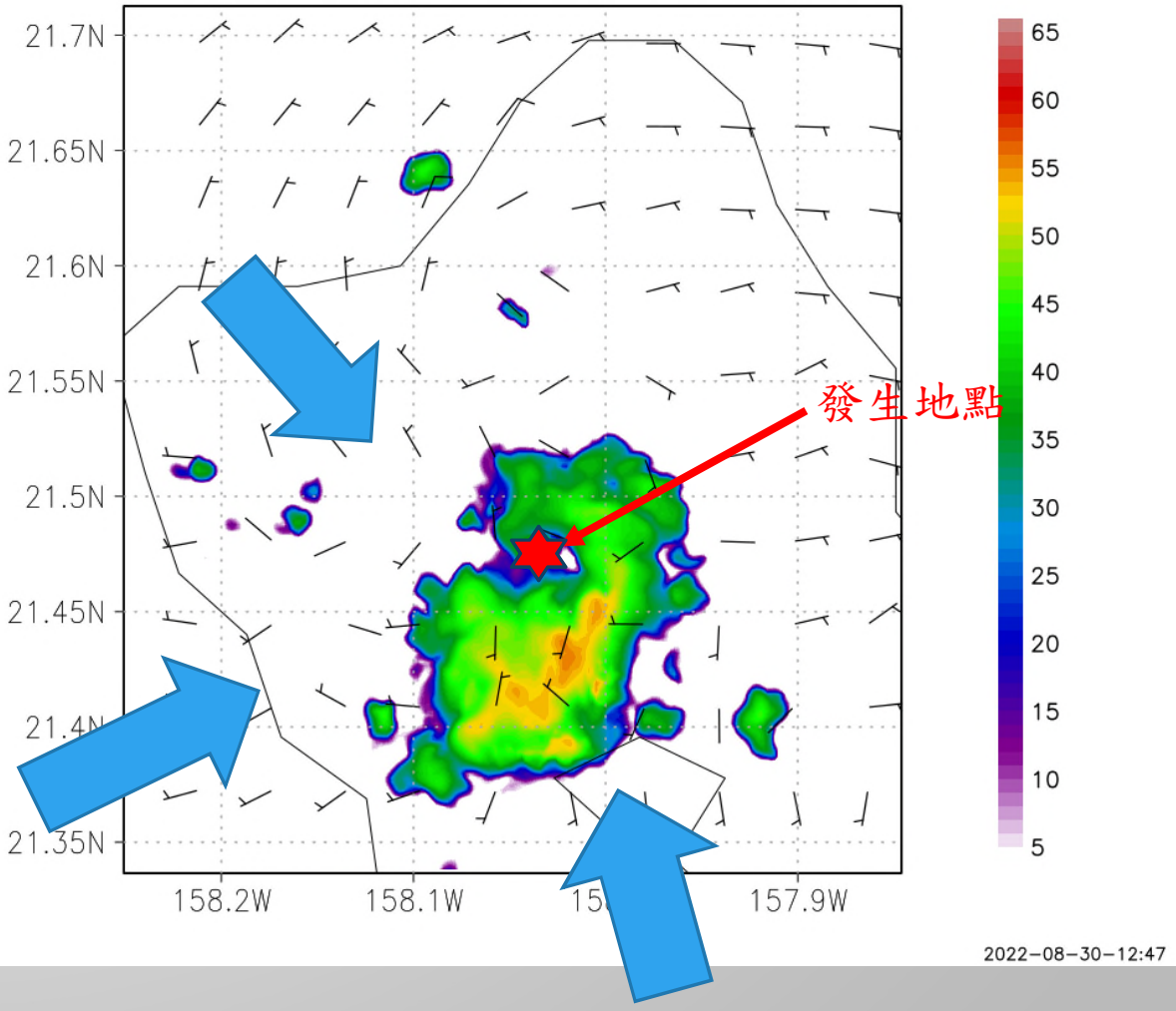
Failed simulated!!

2013-06-08 0000UTC

OBS

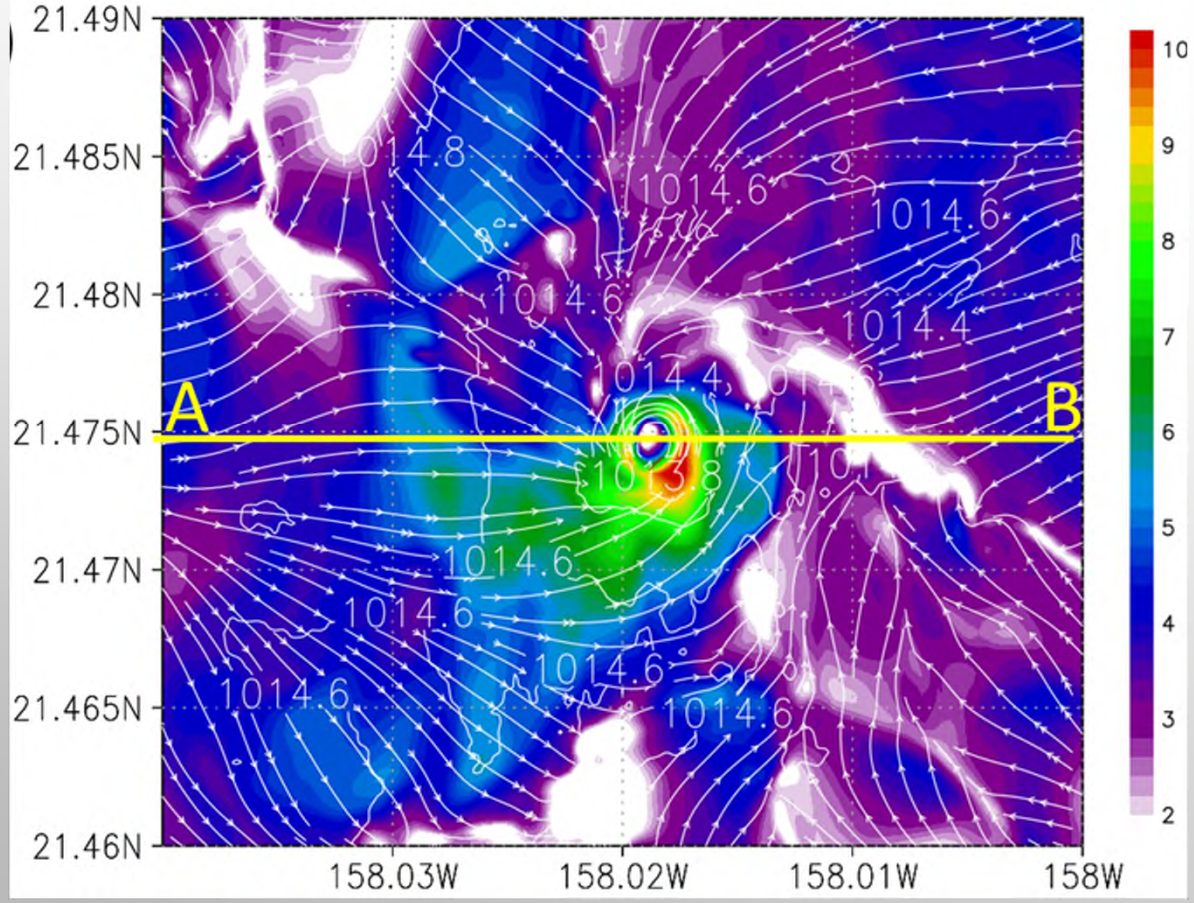


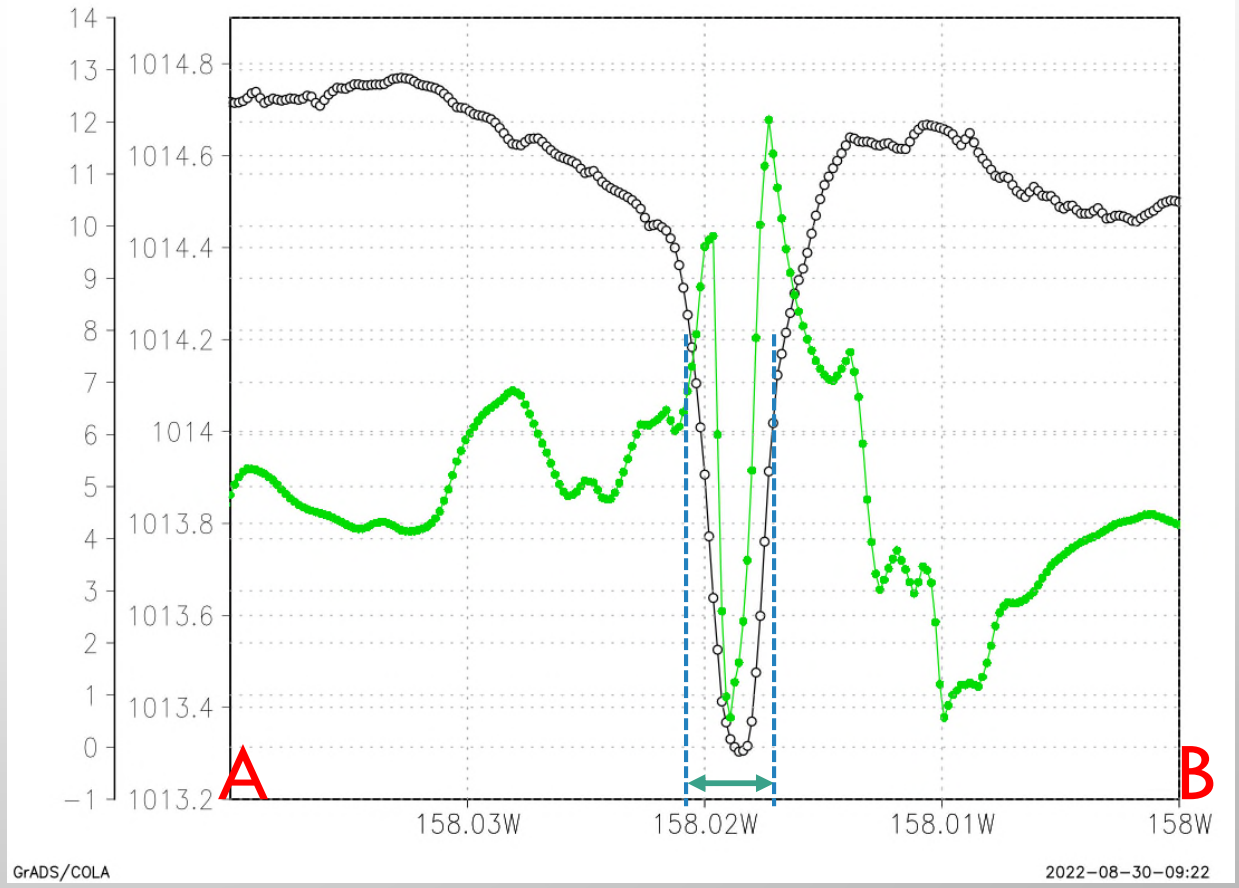
WRF D02 (200M)



模式結果

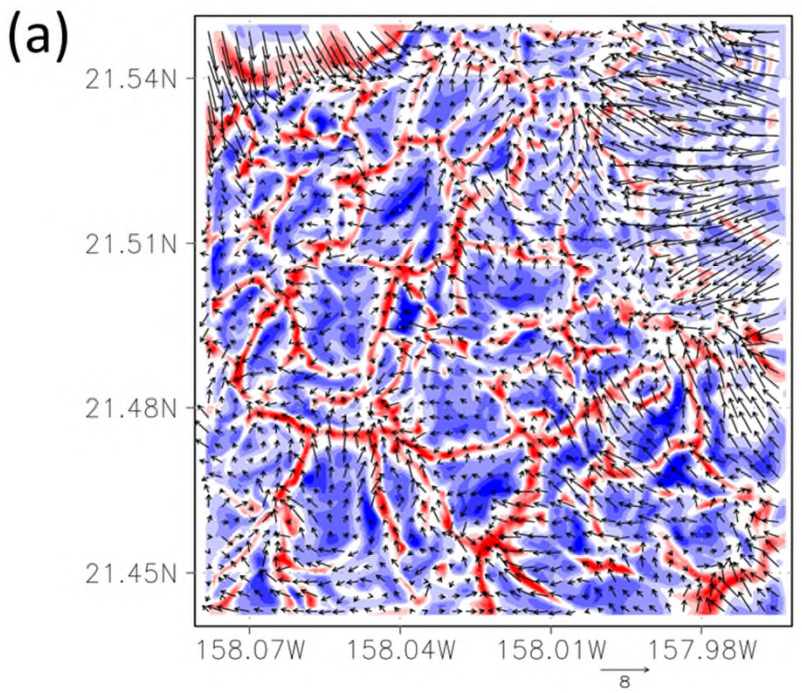
deltaP ~ 1.4hpa, Vmax~27 kts, size ~ 500m



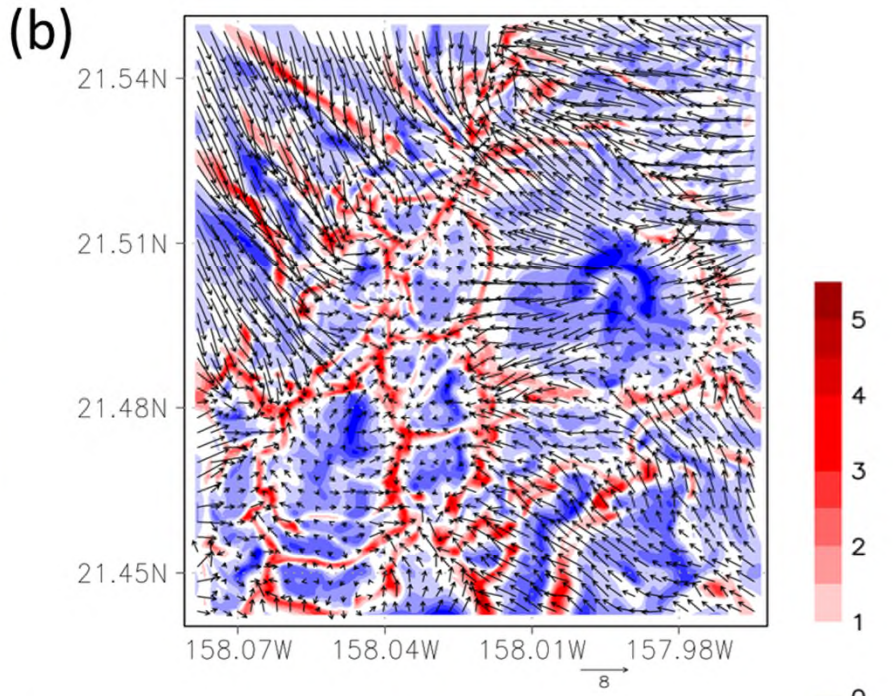


分析討論

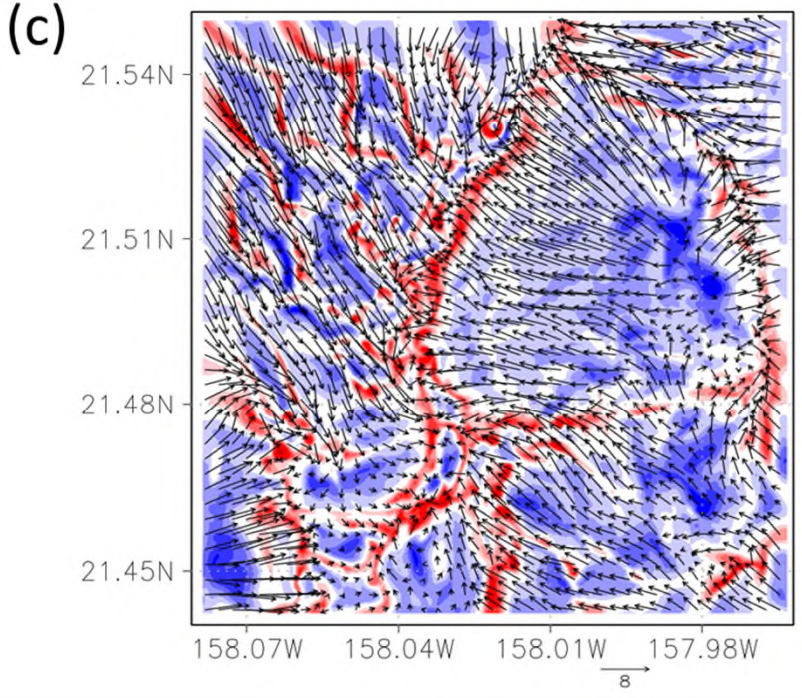
2306 UTC 7 June.



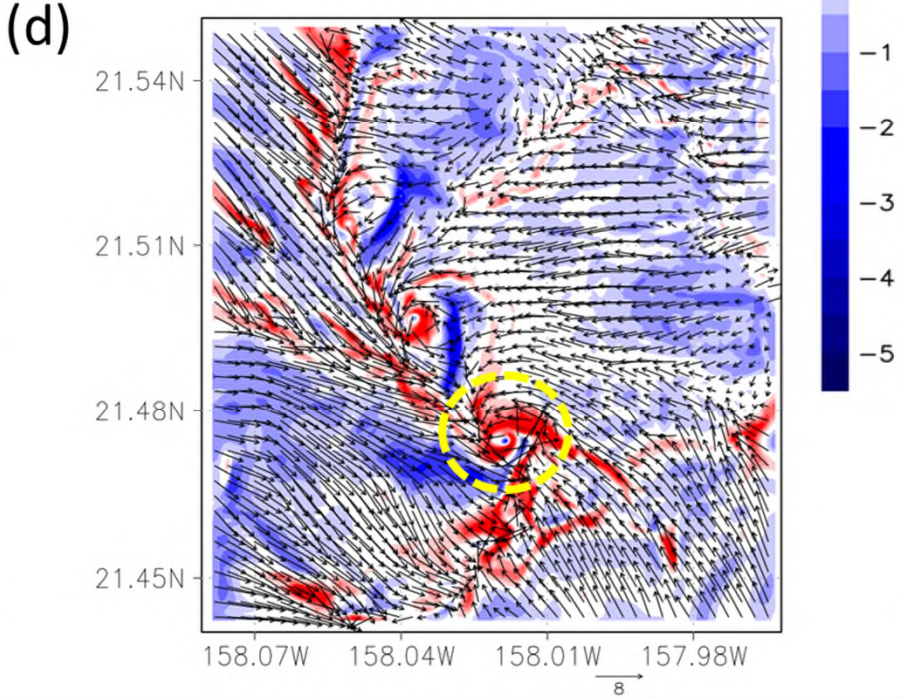
2314 UTC 7 June.



2319 UTC 7 June.



2326 UTC 7 June.



2306 UTC 7 June.

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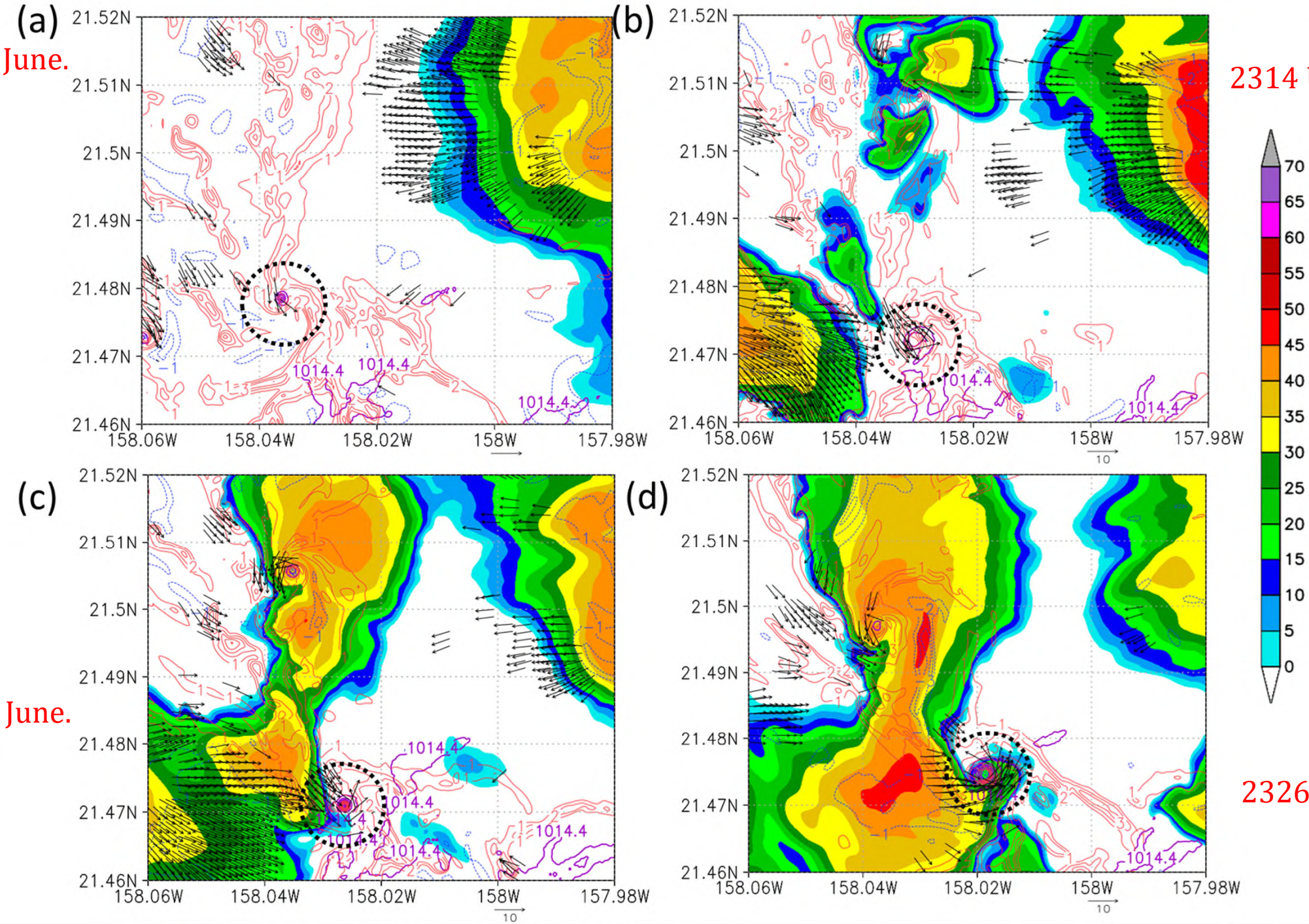

2319 UTC 7 June.

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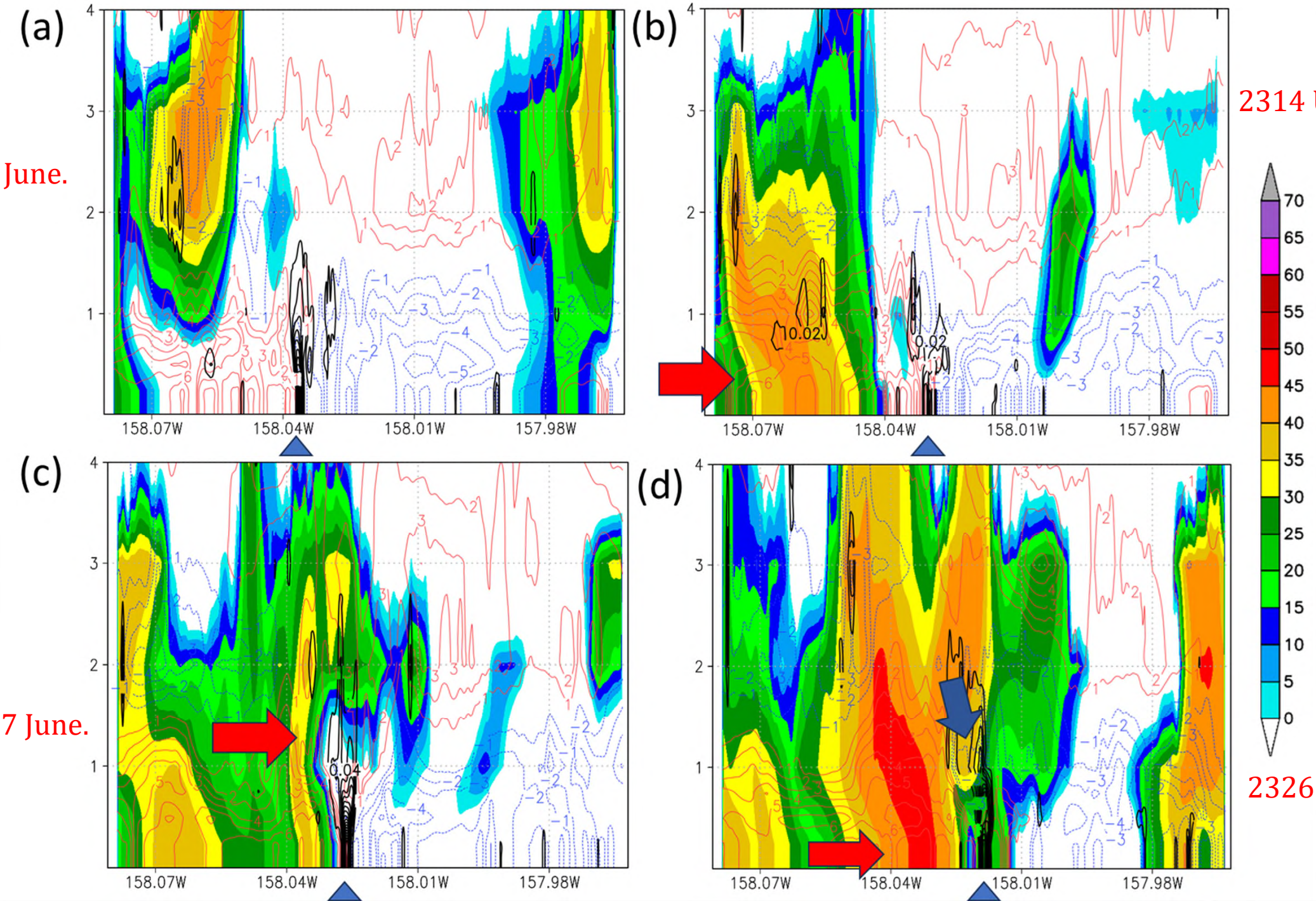

2306 UTC 7 June.

2314 UTC 7 June.

2319 UTC 7 June.

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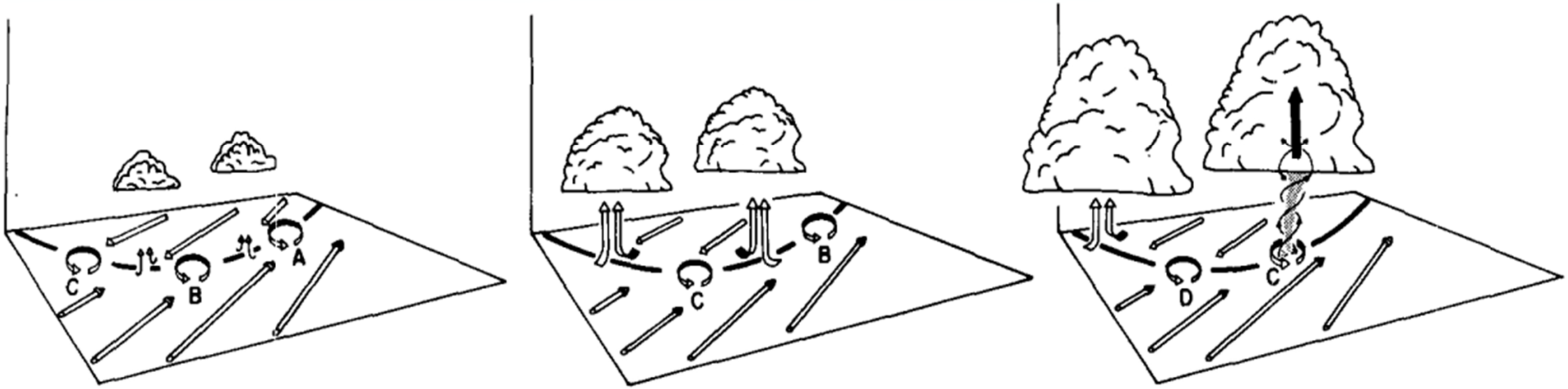


FIG. 20. Schematic model of the life cycle of the non-supercell tornado. The black line is the radar detectable convergence boundary. Low-level vortices are labeled with letters.

微旋渦與對流生成研究

- Landsoupt：30 分鐘內形成，母雲 **非超級胞**；關鍵在 **垂直渦度伸長**（Bluestien, 1985）
- **邊界強切變**：伴隨波動狀擾動 → **1–3 km 渦度環流**，促使風暴迅速發展（Wakimoto & Wilson, 1989）
- **微旋渦（misocyclones）**：沿邊界移動並被伸長（Brady & Szoke, 1989）
- **切變不穩定** 生成微旋渦；**龍捲起源自地表**，渦度伸長為主要增強機制（Lee & Wilhelmson, 1997）

渦度收支分析

$$\frac{\partial \zeta}{\partial t} = -\left(u\frac{\partial \zeta}{\partial x} + v\frac{\partial \zeta}{\partial y}\right) - \left(u\frac{\partial f}{\partial x} + v\frac{\partial f}{\partial y}\right) - \omega\frac{\partial \zeta}{\partial p} + \left(\frac{\partial \omega}{\partial y}\frac{\partial u}{\partial p} - \frac{\partial \omega}{\partial x}\frac{\partial v}{\partial p}\right) - (\zeta + f)\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)$$

趨勢項

水平平流

行星渦度平流

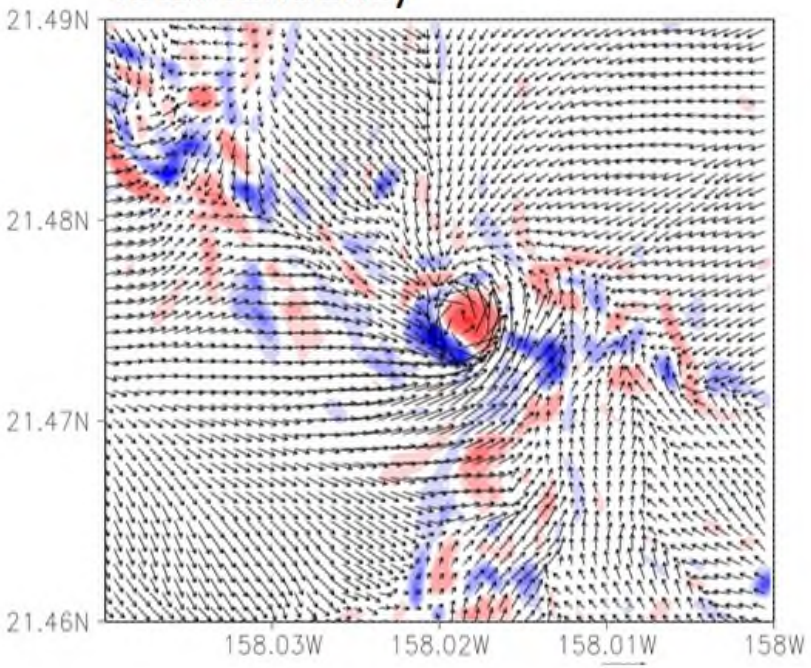
（量值太小，不列入分析）

垂直平流

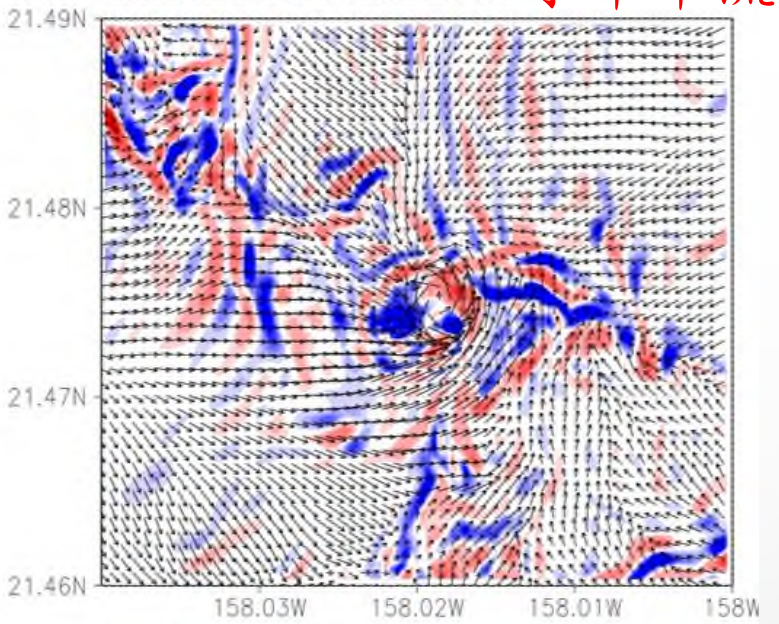
傾斜項

抽拉項

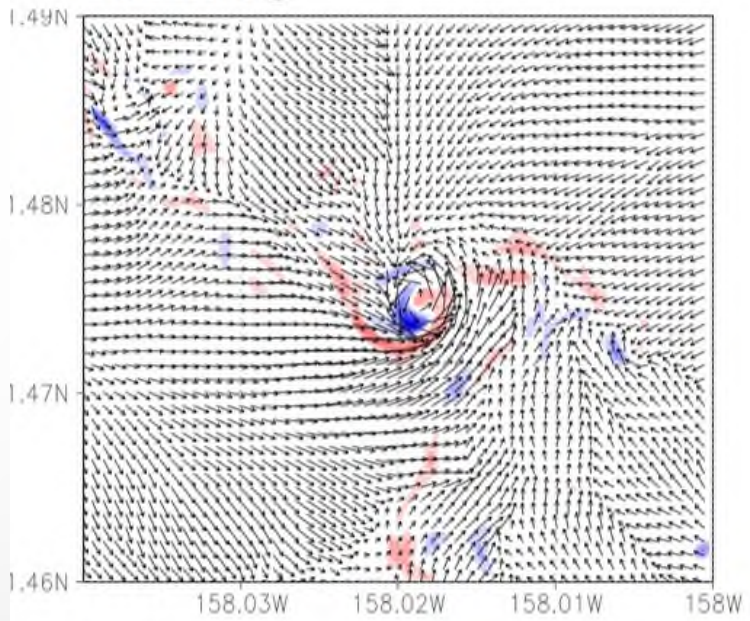
Total tendency 趨勢項



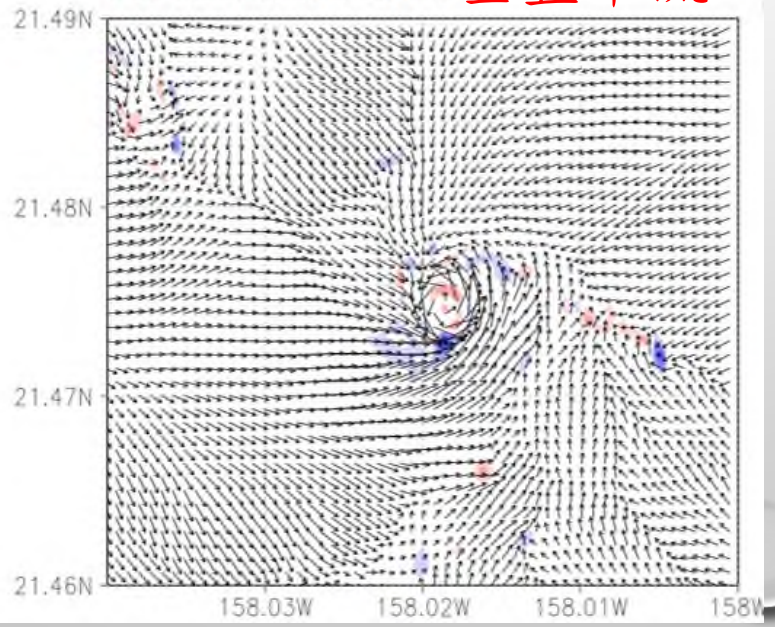
Horizontal advection 水平平流



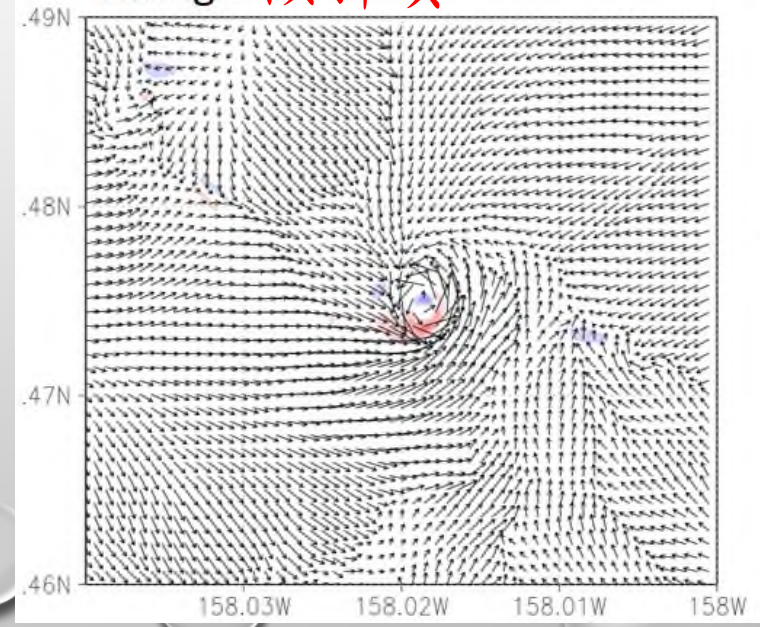
Stretching 抽拉項



Vertical advection 垂直平流

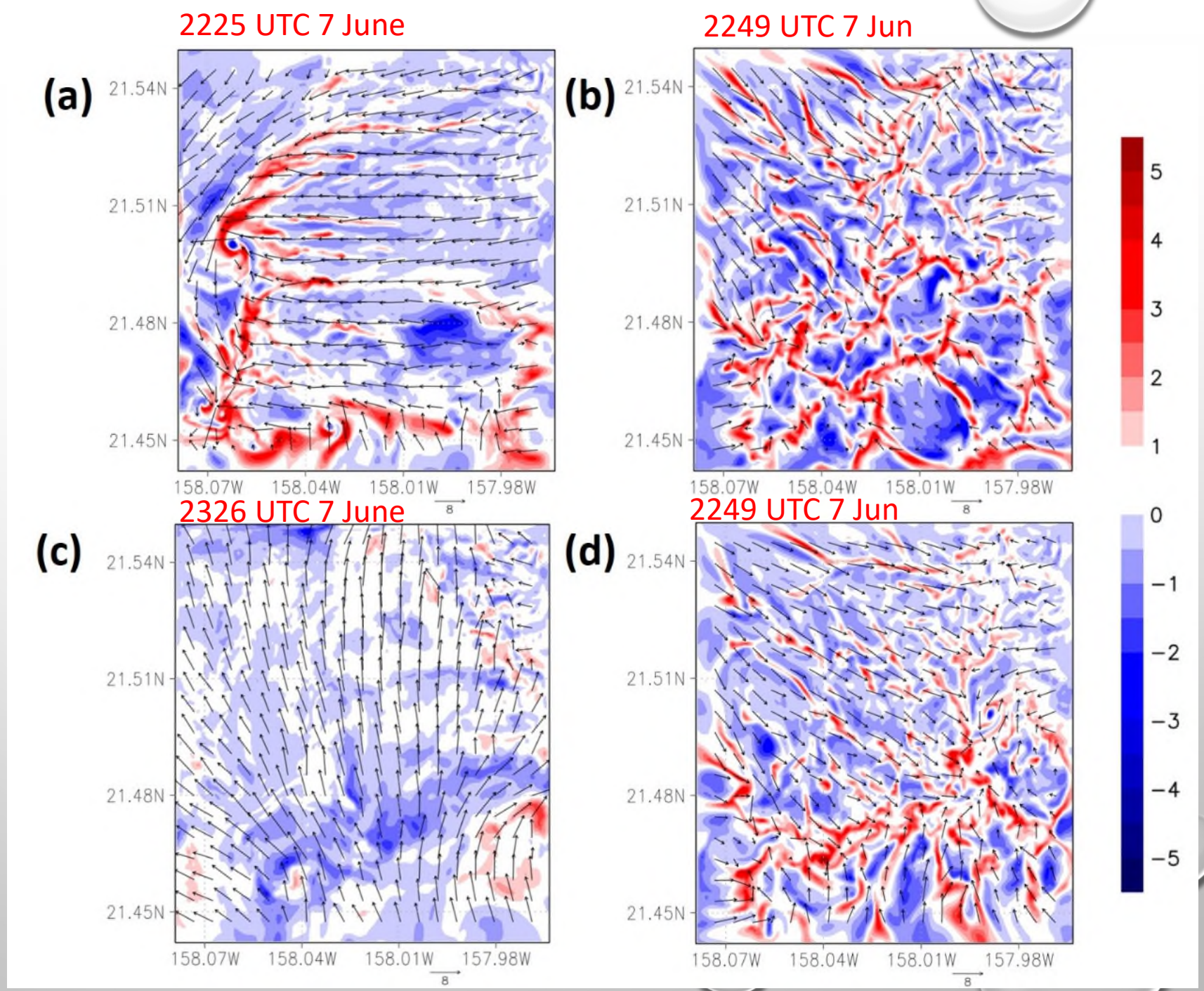


Tilting 傾斜項

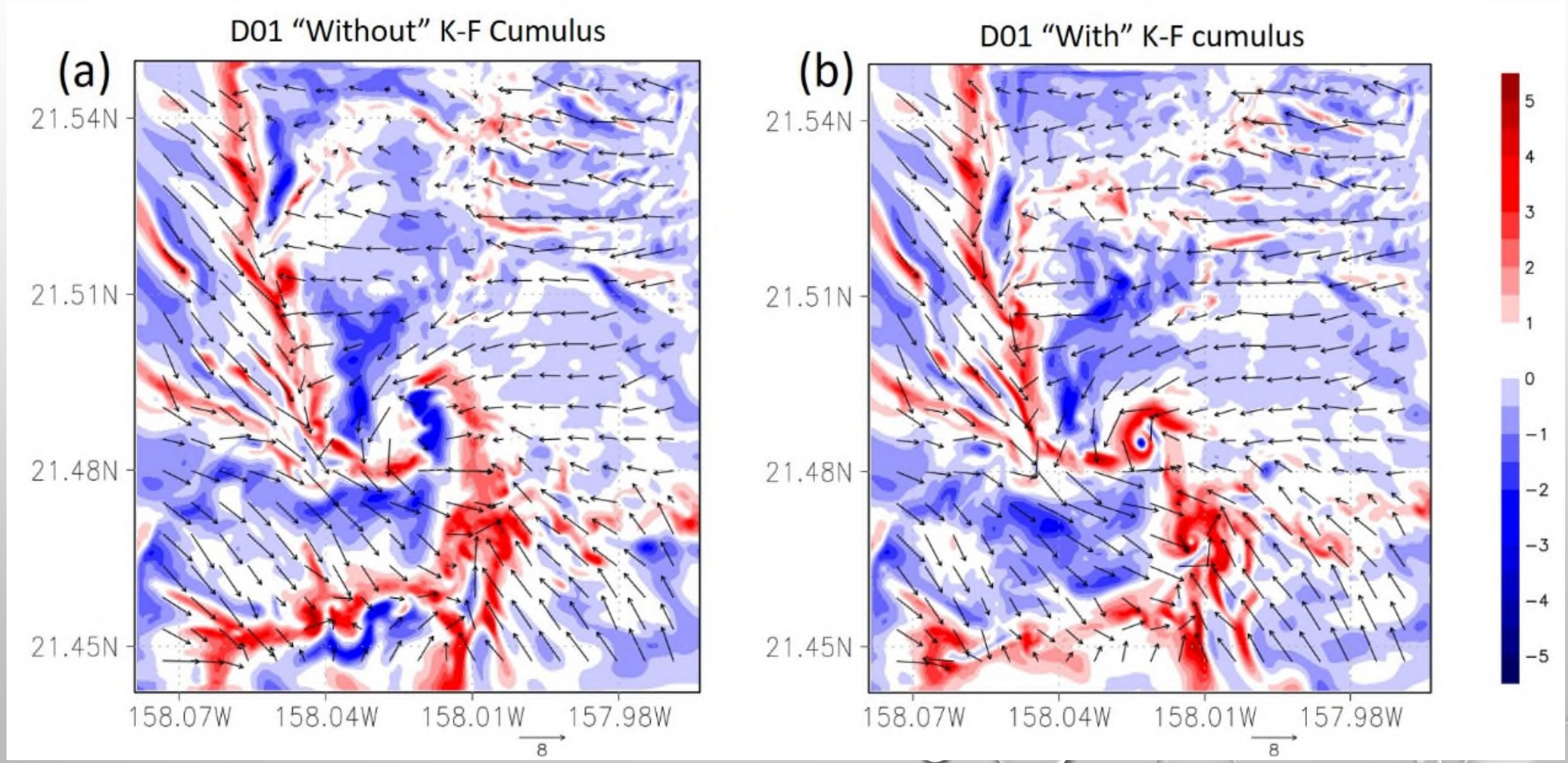


相對溼度敏感實驗

LiRH20	**Increasing low-level (1000-850mb) RH 20%**
LrRH20	Reducing low-level RH (1000-850mb) 20%

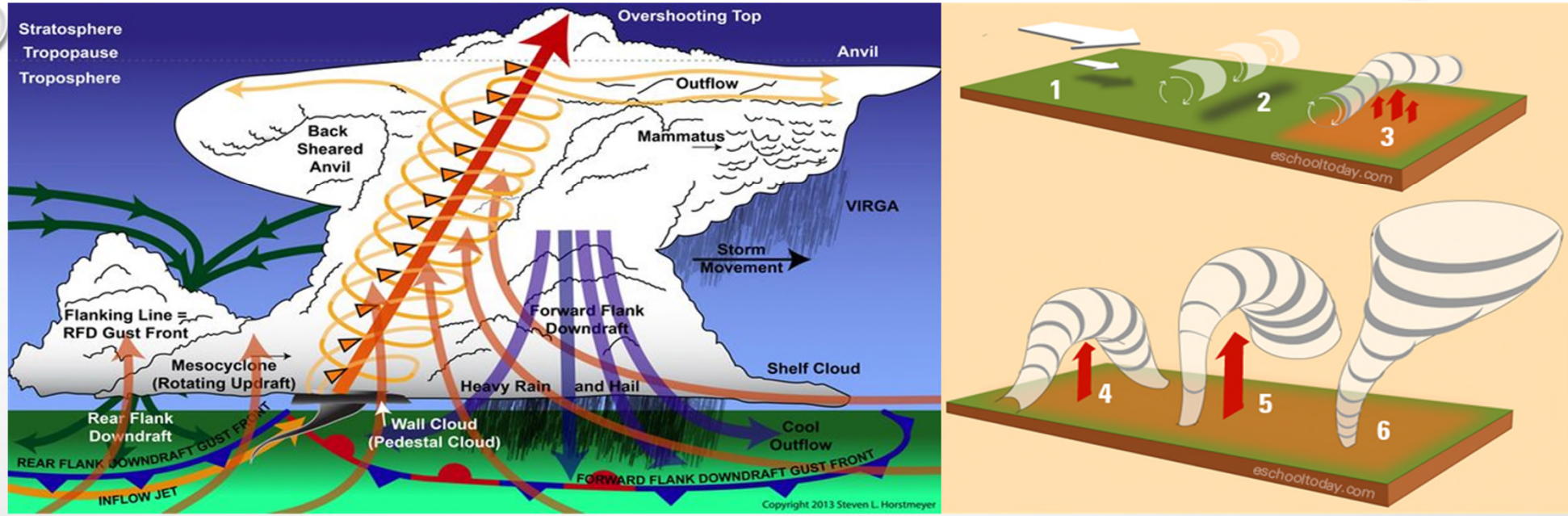


積雲參數化敏感實驗

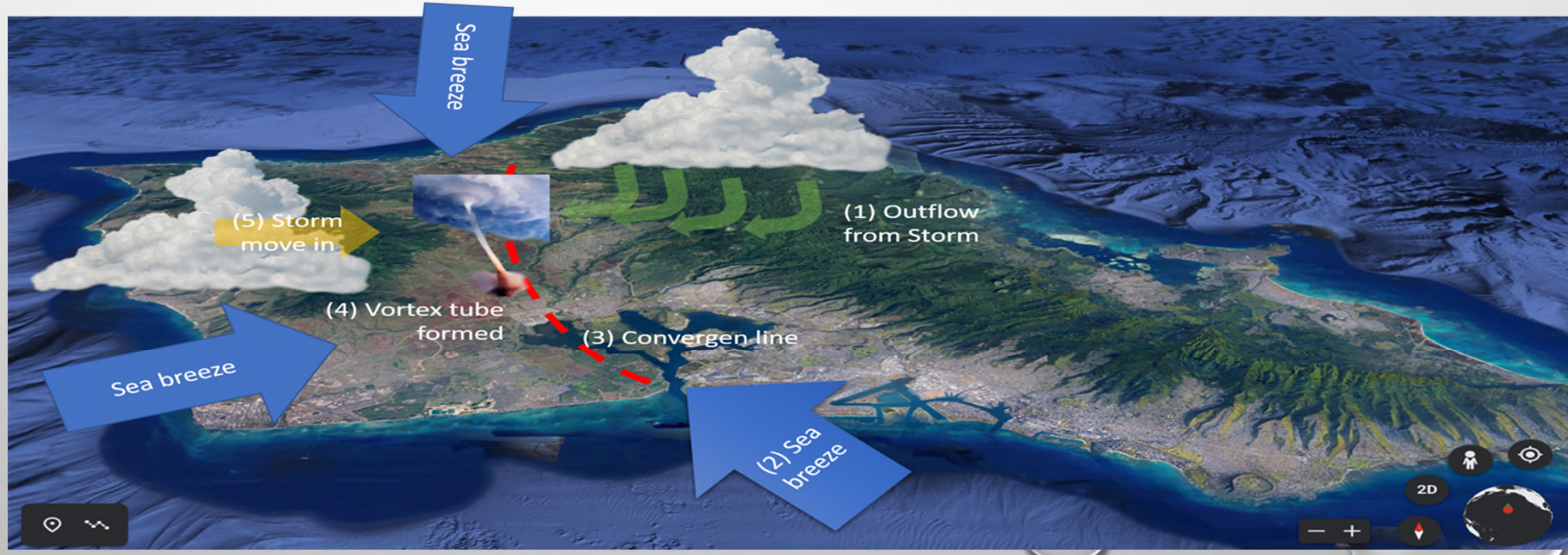

D01 "Without" K-F Cumulus
(a)
21.54N
21.51N
21.48N
21.45N
158.07W
158.04W
158.01W
157.98W
8
D01 "With" K-F cumulus
(b)
21.54N
21.51N
21.48N
21.45N
158.07W
158.04W
158.01W
157.98W
8
5
4
3
2
1
0
−1
−2
−3
−4
−5

Super-Cell Tornadoes

(a)



(b)



NSC or Mini-Cell Tornadoes over complex terrain/island

典型超級胞龍捲 VS 弱島嶼龍捲

典型超級胞龍捲
(Supercell Tornado)

大尺度垂直風切變
↓
形成水平渦管(水平)
↓
上升氣流直立化
↓
垂直渦旋
↓
龍捲形成

弱島嶼龍捲 (Weak Island Tornado)

陸風－海風交會 + 冷池外流
↓
局部水平渦旋(直立)
↓
渦管伸長
↓
渦度增強
↓
快速龍捲形成 (7－8 分鐘)

結論

- ✓ 歐胡島40m 網格解析度 → 成功模擬「類龍捲渦旋」
- ✓ 熱帶島嶼龍捲形成可能條件：
  - 大尺度環境條件
  - 局部環流(如：海陸風)
  - 鄰近對流系統的強烈外流（非常重要!）
- ✓ 從渦度收支分析發現，除水平平流項外，抽拉項為主要貢獻項。
- ✓ 敏感度實驗顯示，低層水氣影響前置地面渦漩出現與否，且相當敏感。
- ✓ 粗解析度積雲參數化會影響對流發展強度，且影響後續渦漩生成。