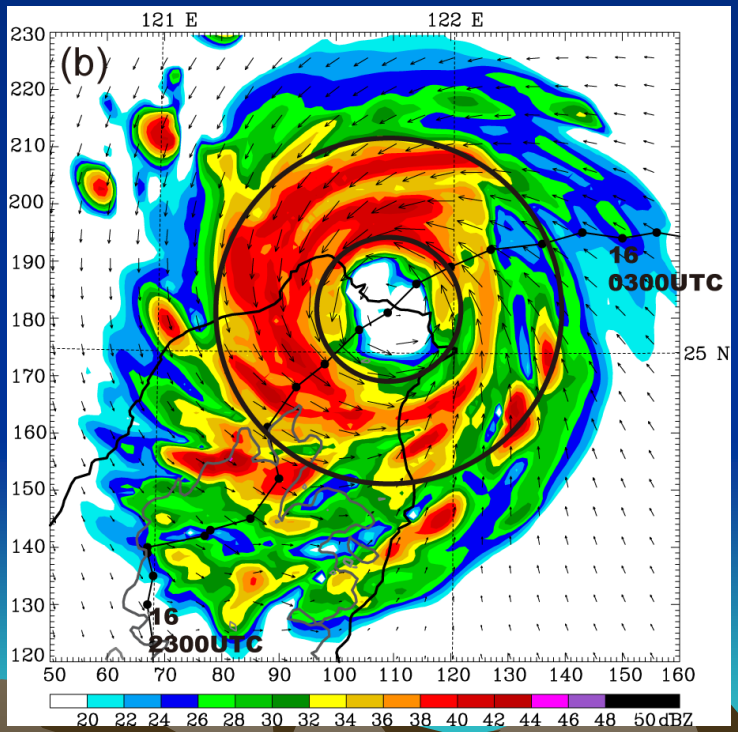
台灣地形對於颱風的影響
Taiwan's Orographic Effects on Typhoons

楊明仁

大氣科學系 & 水文暨海洋科學研究所

國立中央大學



2012/06/01 @ 國立高雄師範大學地理系

颱風災害→數十至百億台幣經濟影響

直接颱風災害（風災、水災、土石流）

颱風放假與防災動員(遷村、撤離)

水資源規劃管理(水庫操作、自來水供應)

科學議題:

颱風路徑預報

颱風伴隨風雨預報

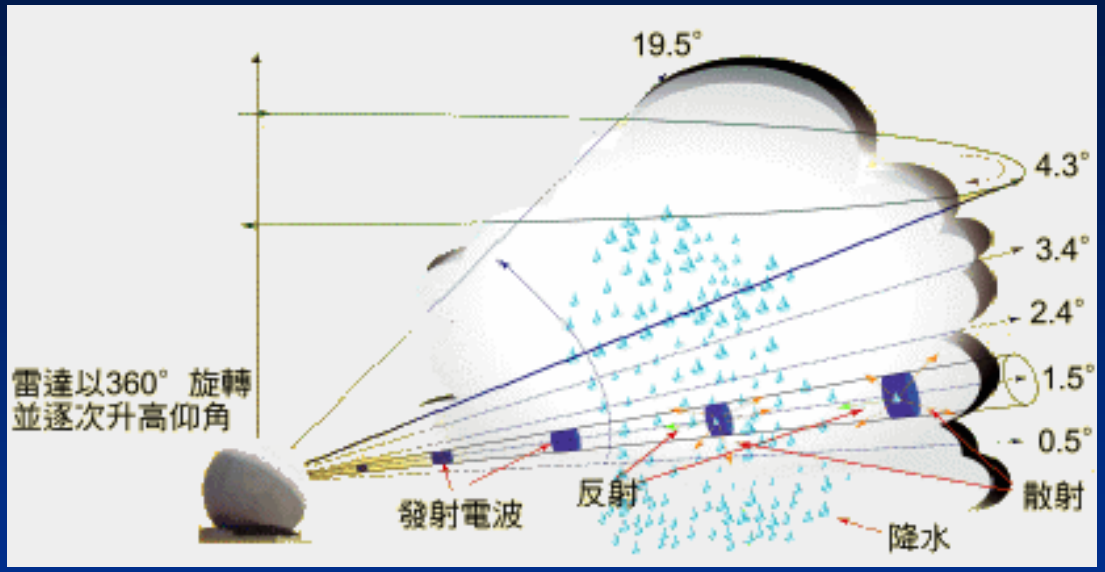
颱風個數季節預報

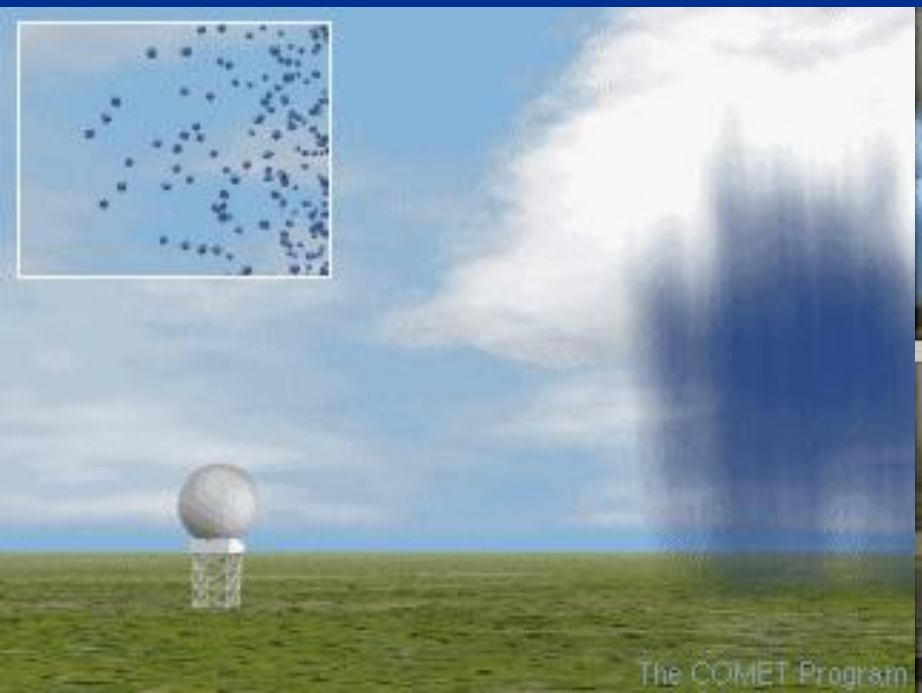
颱風基本結構
Structure of Typhoon

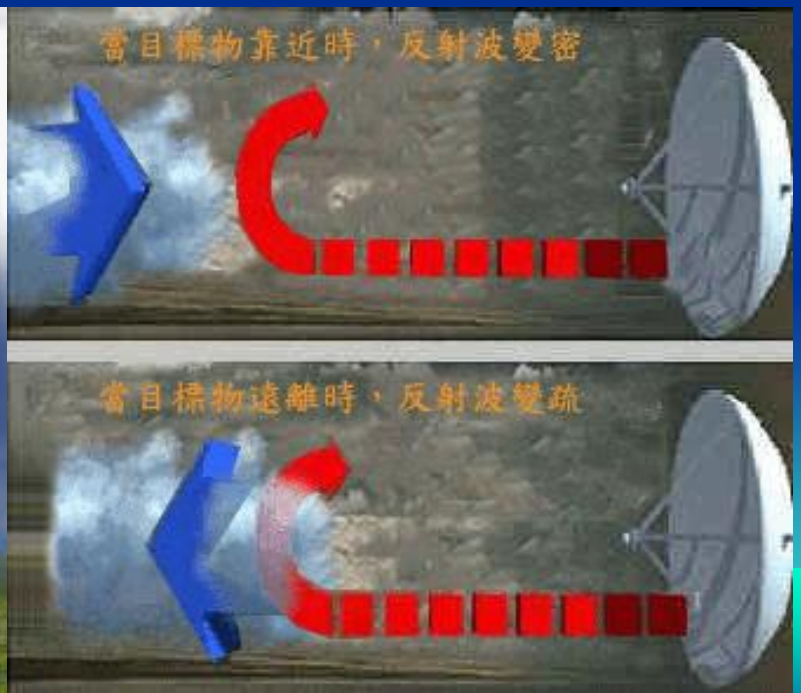
都卜勒氣象雷達

a. 利用反射波強度知雨滴大小

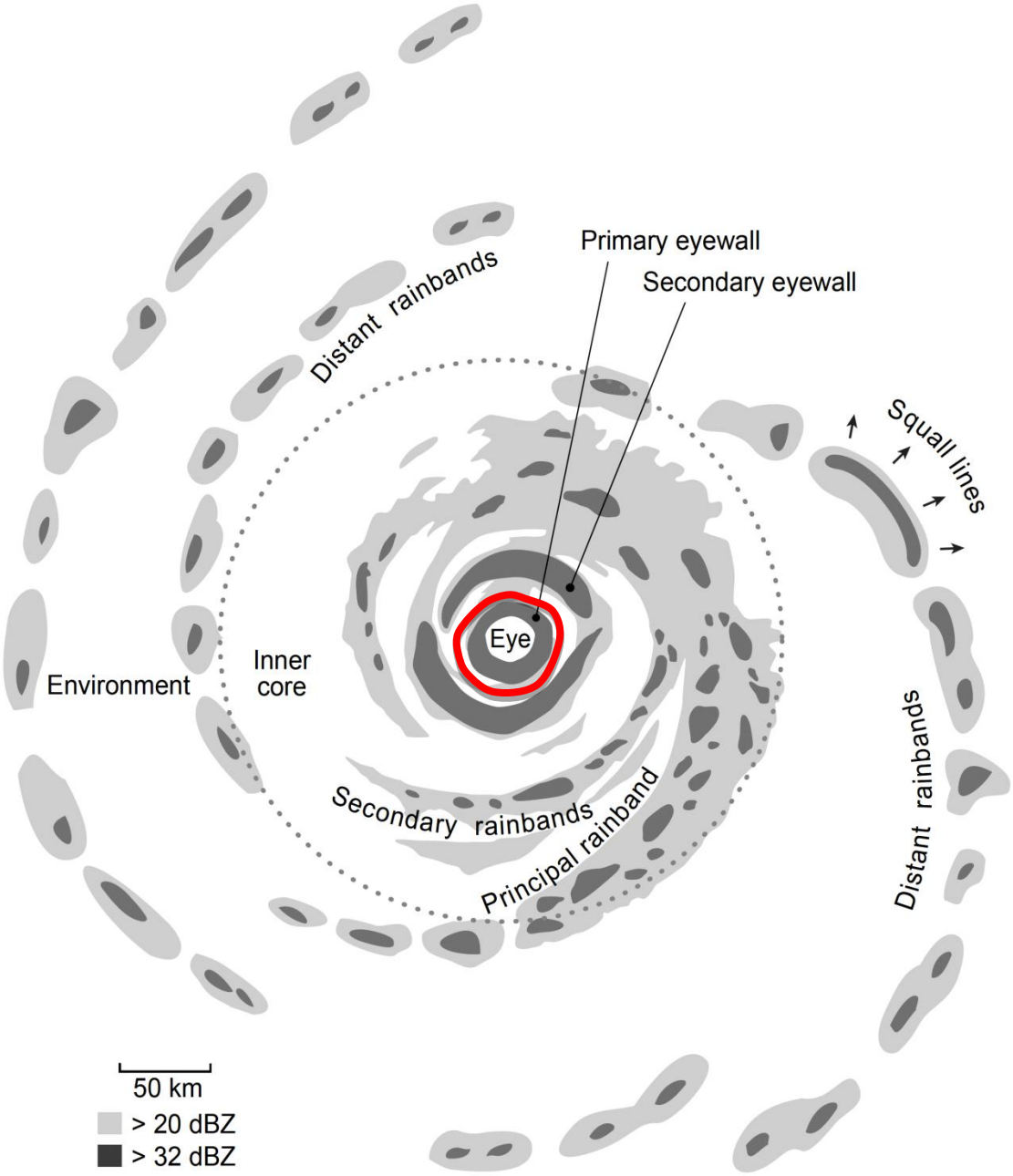
b. 利用反射波波長變化知移動速度及方向





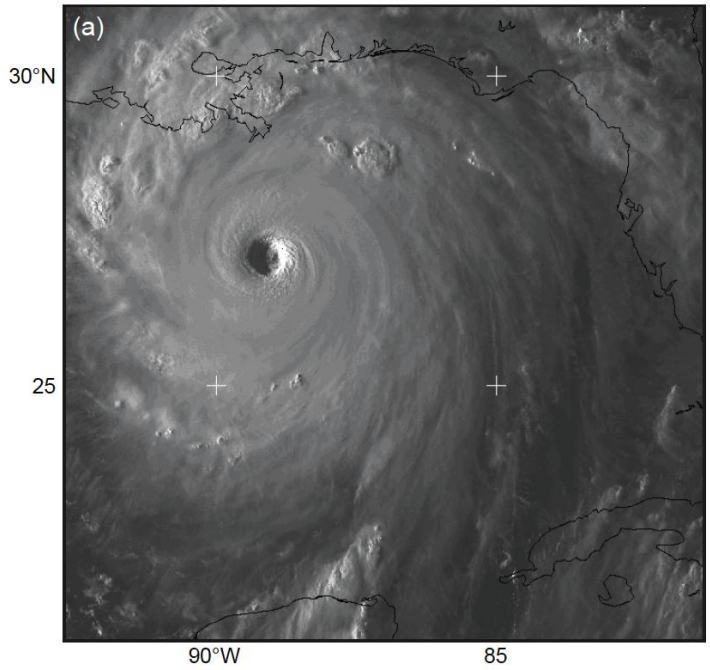


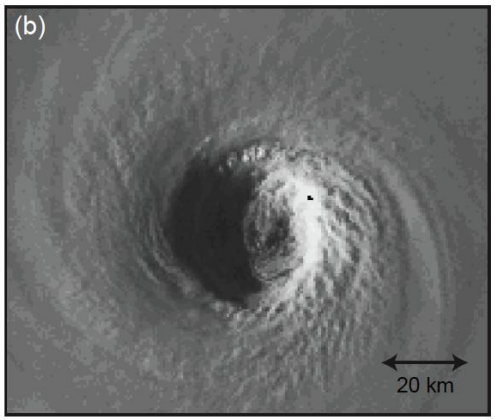
雷達回波



Houze 2010

颱風眼及眼牆Eye & Eyewall

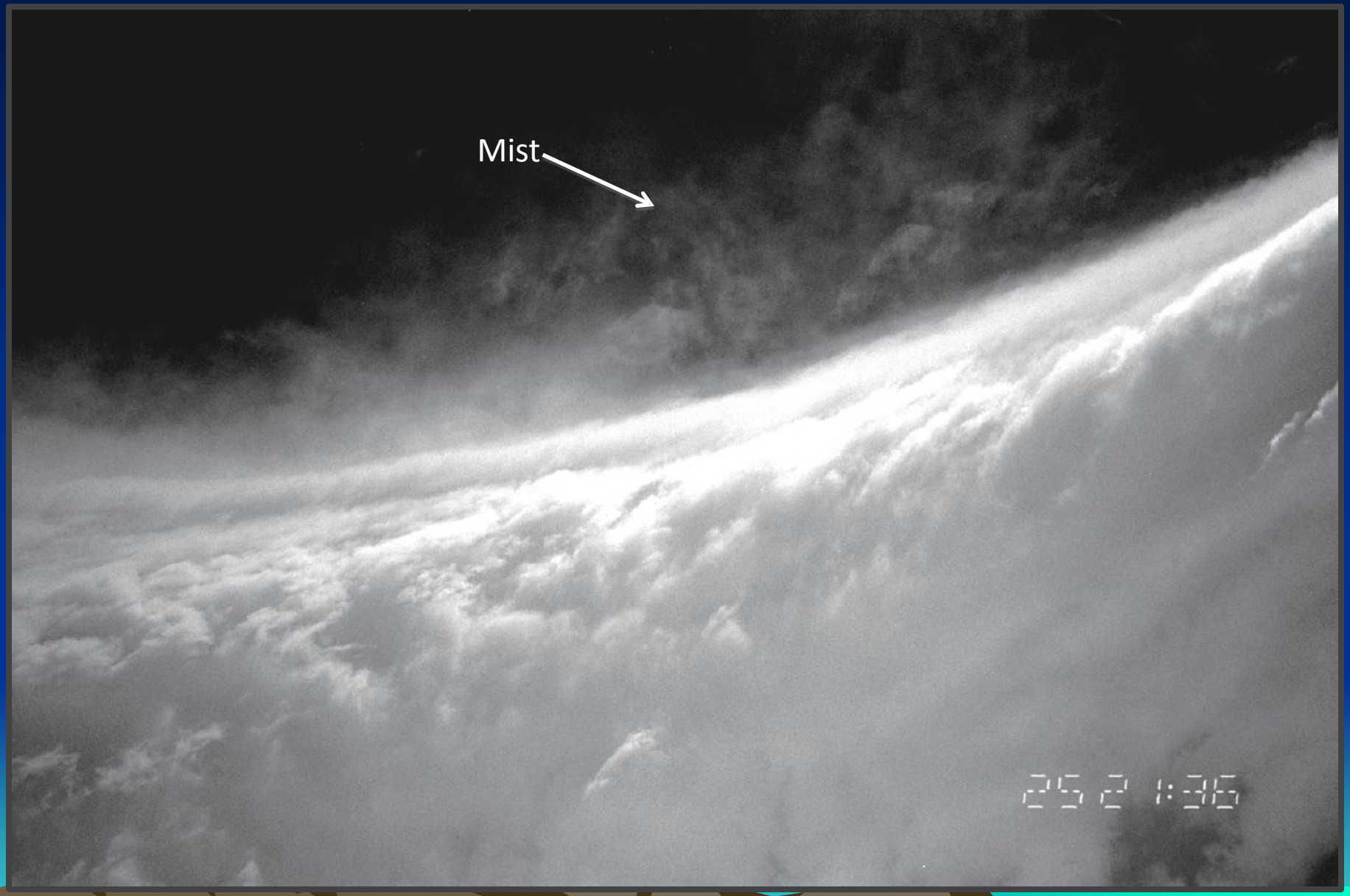




Sloping eyewall

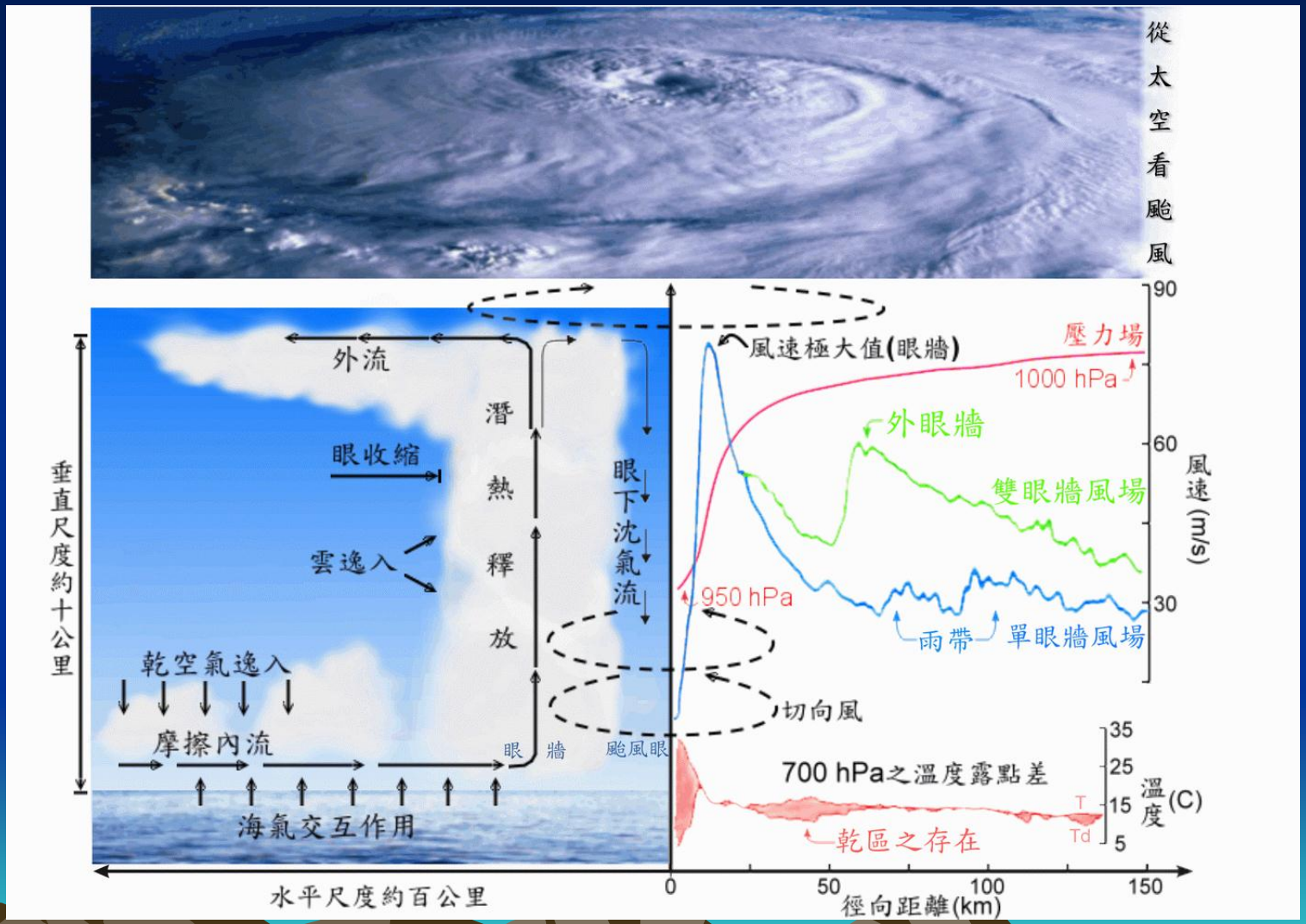
Stratus

Houze 2010

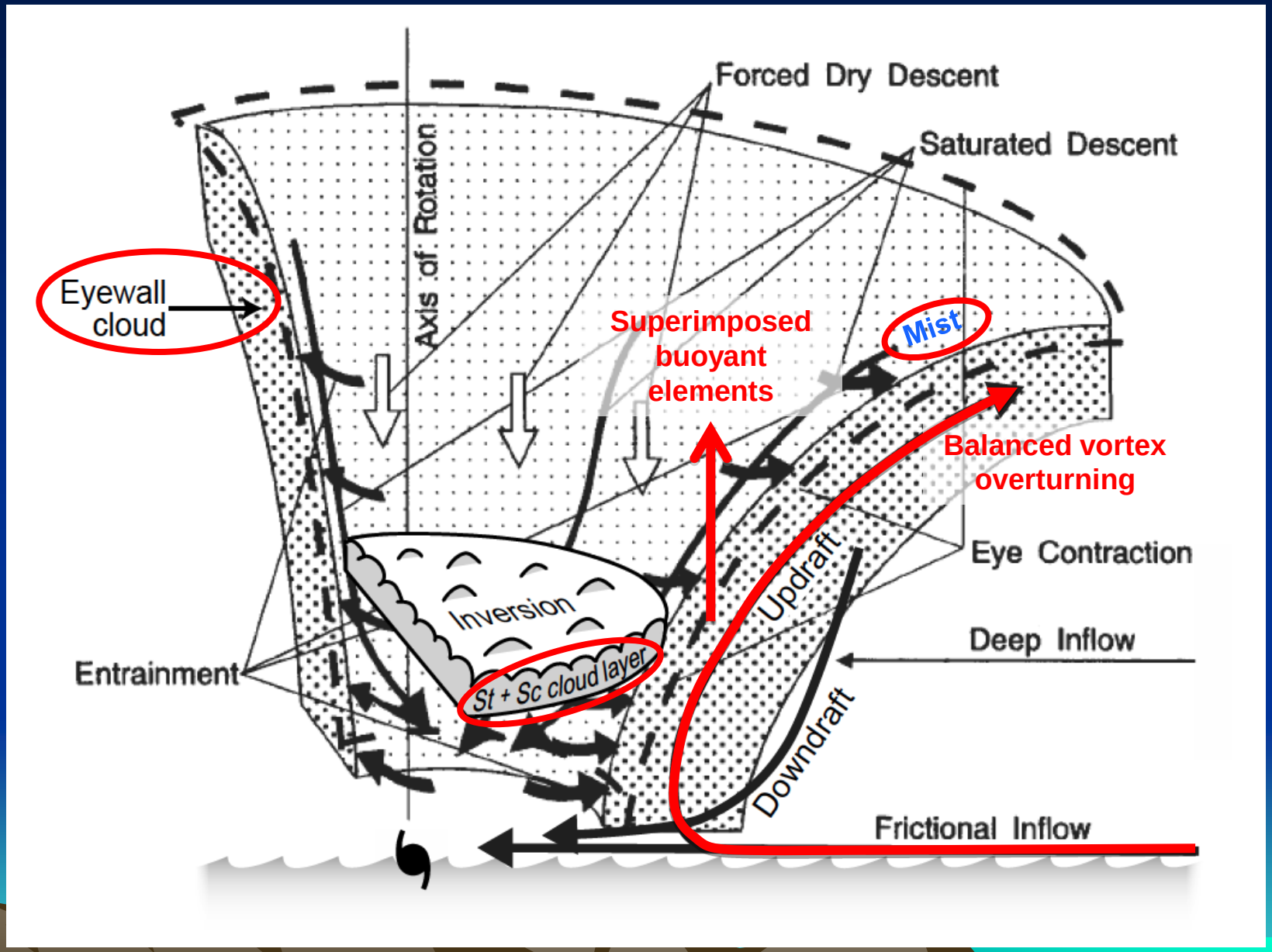


Willoughby 1998

揭開颱風的面紗---颱風的基本結構



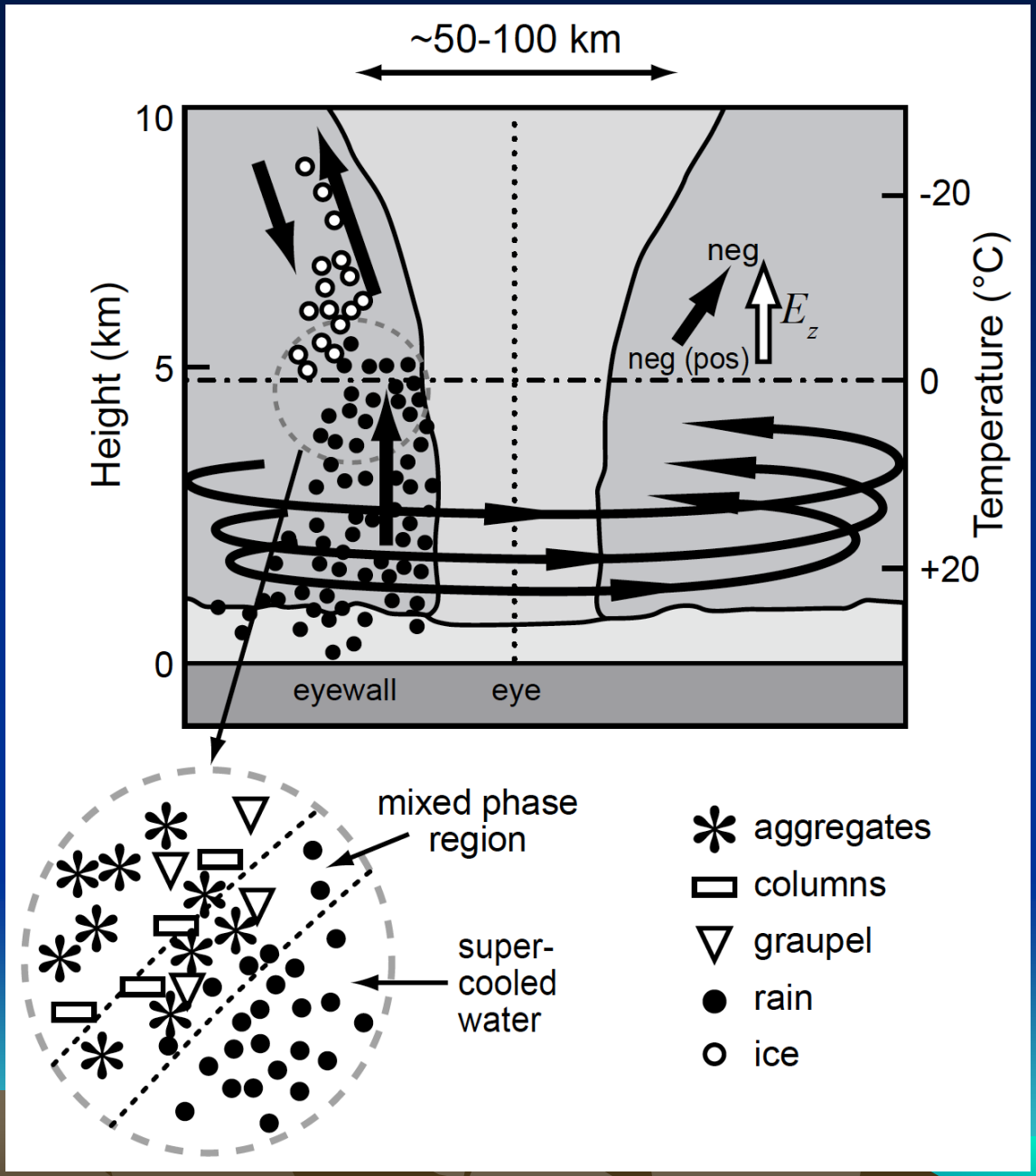
取自郭鴻基,李清勝, 吳俊傑(2001)



Adapted from Willoughby 1998

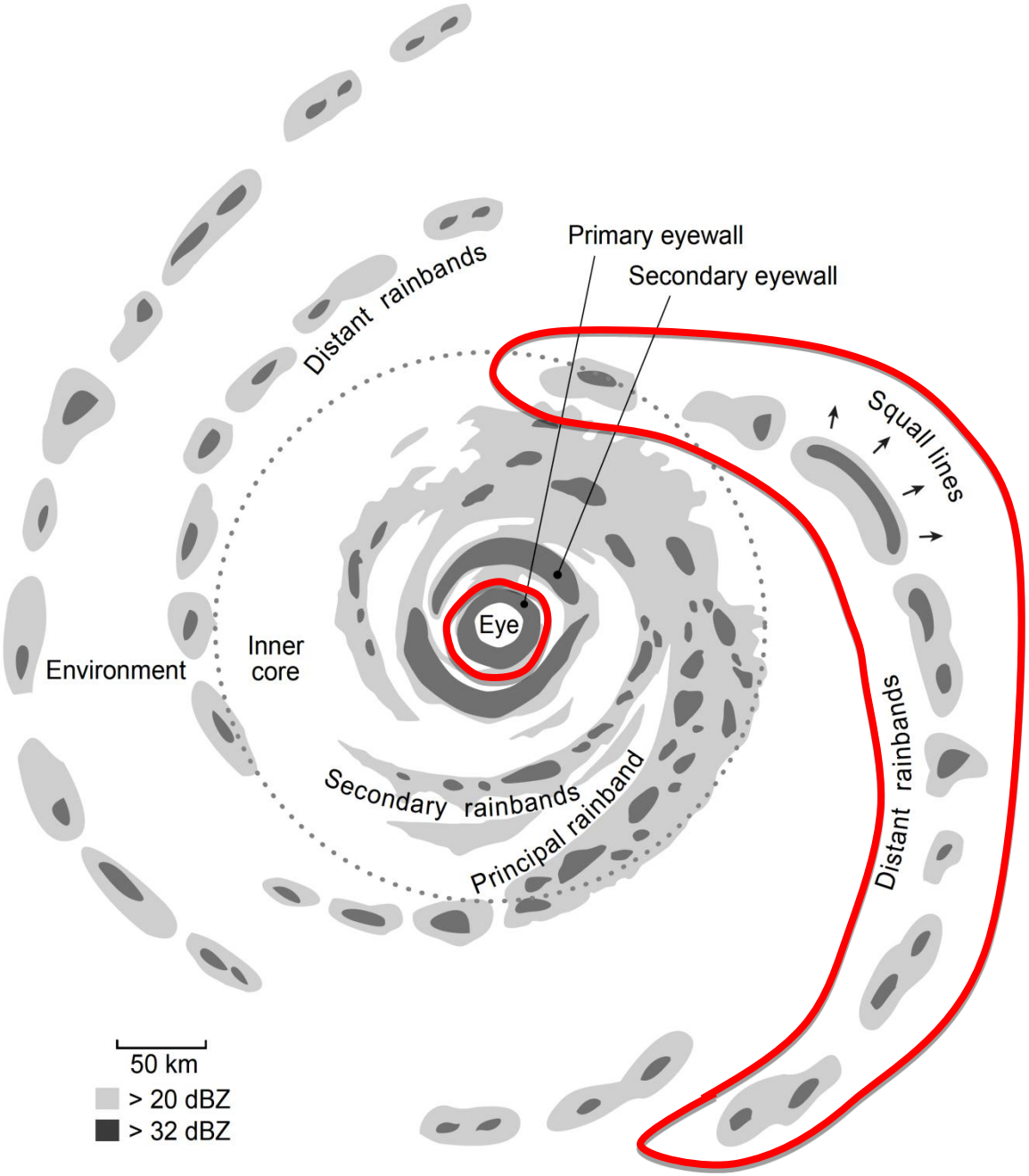
Black &Hallett 1999

230 aircraft flights



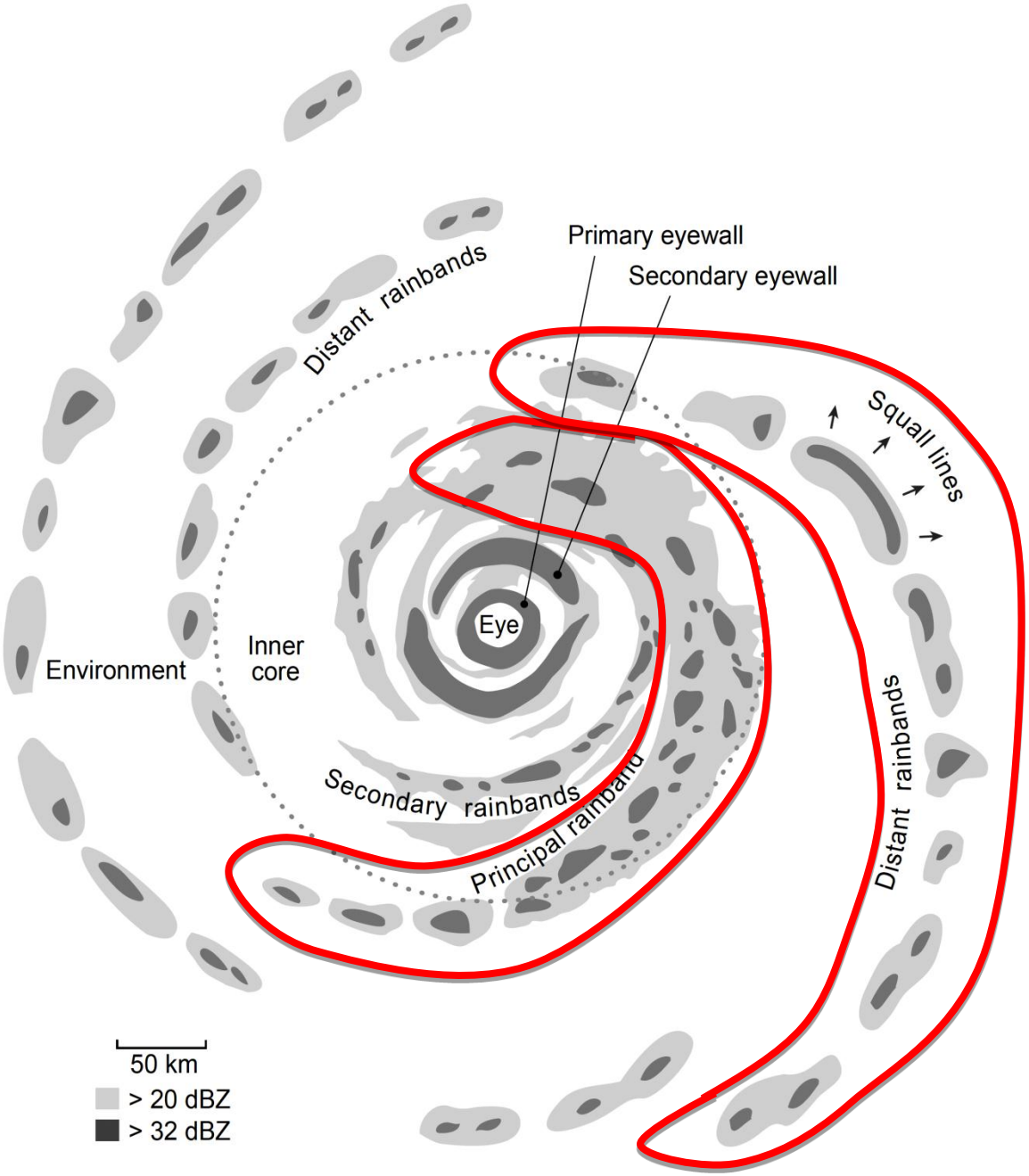
三種螺旋雨帶
Three types of spiral rainbands

1.Distant 遠方雨帶
2.Primary 主要雨帶
3.Secondary 次要雨帶



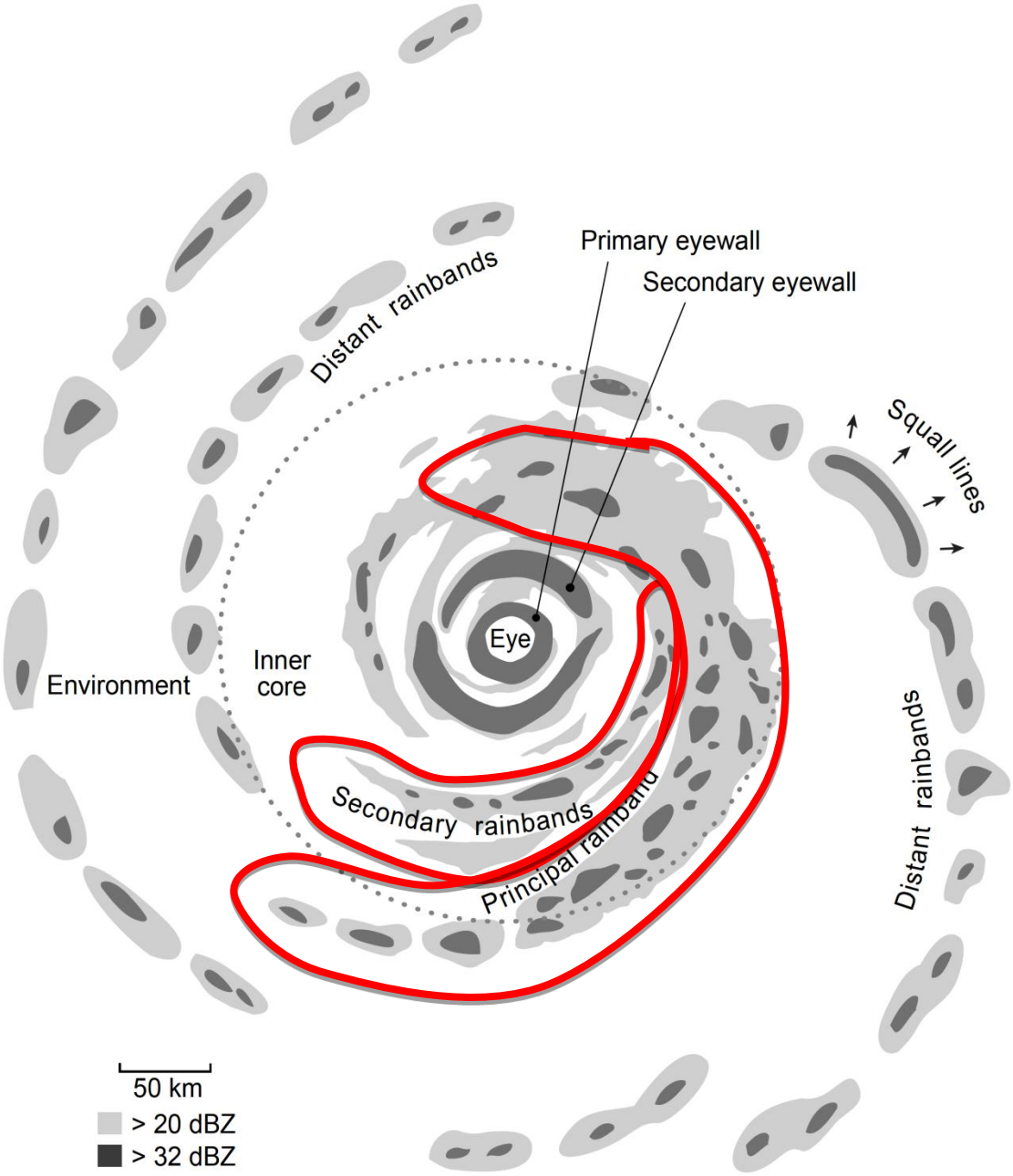
遠方雨帯
&
主要雨帯

Freely adapted from Willoughby 1988



遠方雨帶
&
主要雨帶

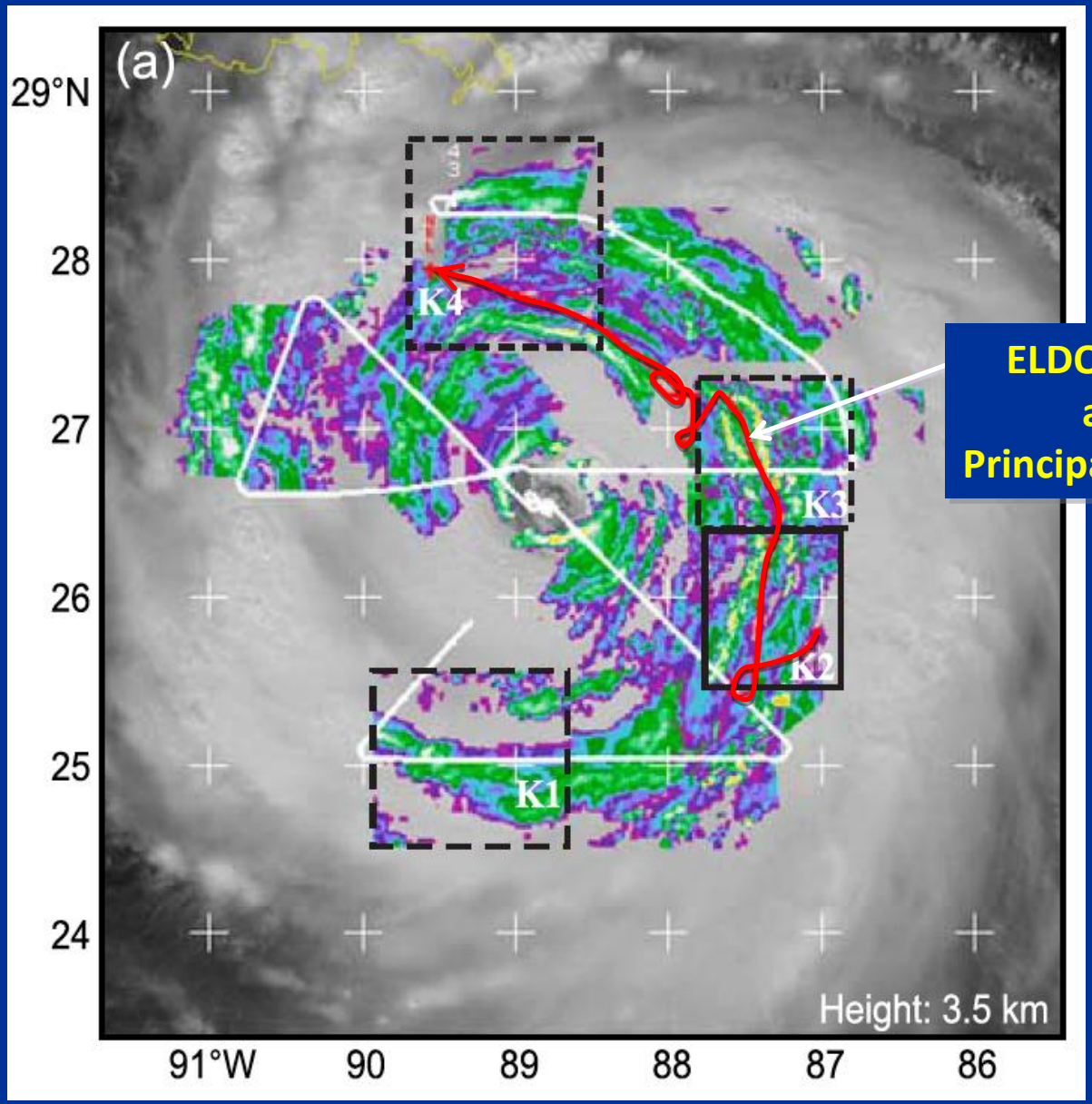
Freely adapted from Willoughby 1988



次要雨帶

Freely adapted from Willoughby 1988

Hurricane Katrina (2005)

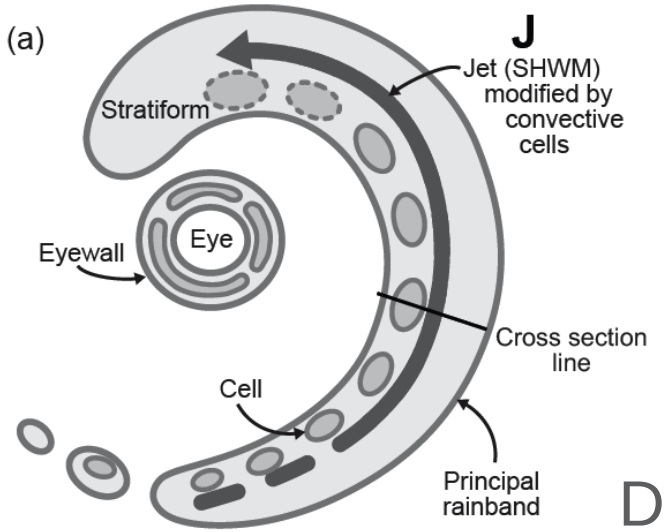


飛機穿越
主要雨帶

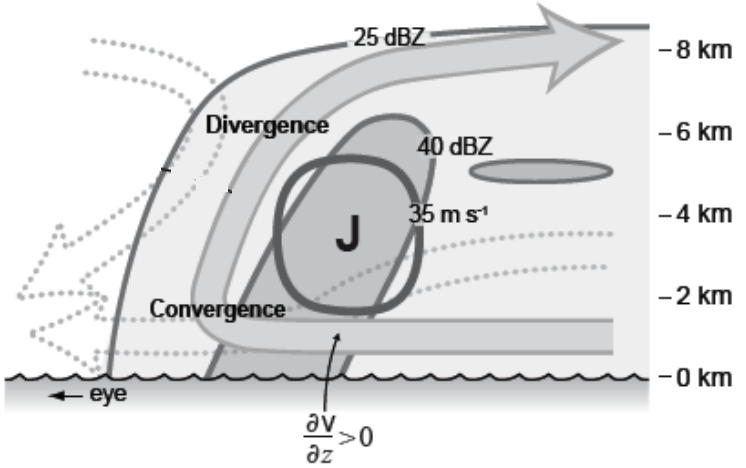
Houze
2010

Convective Structure of the Principal Rainband
主要雨帶之對流結構

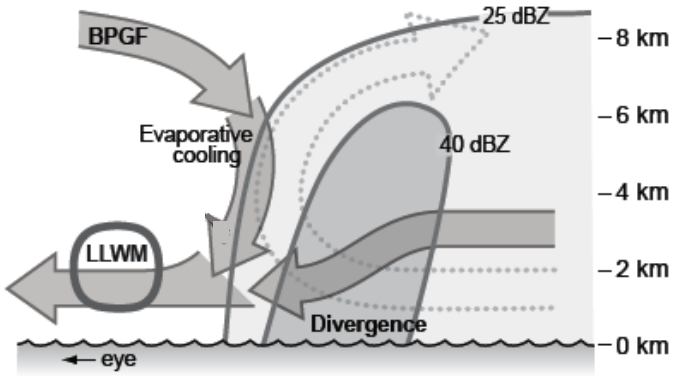
Houze
2010



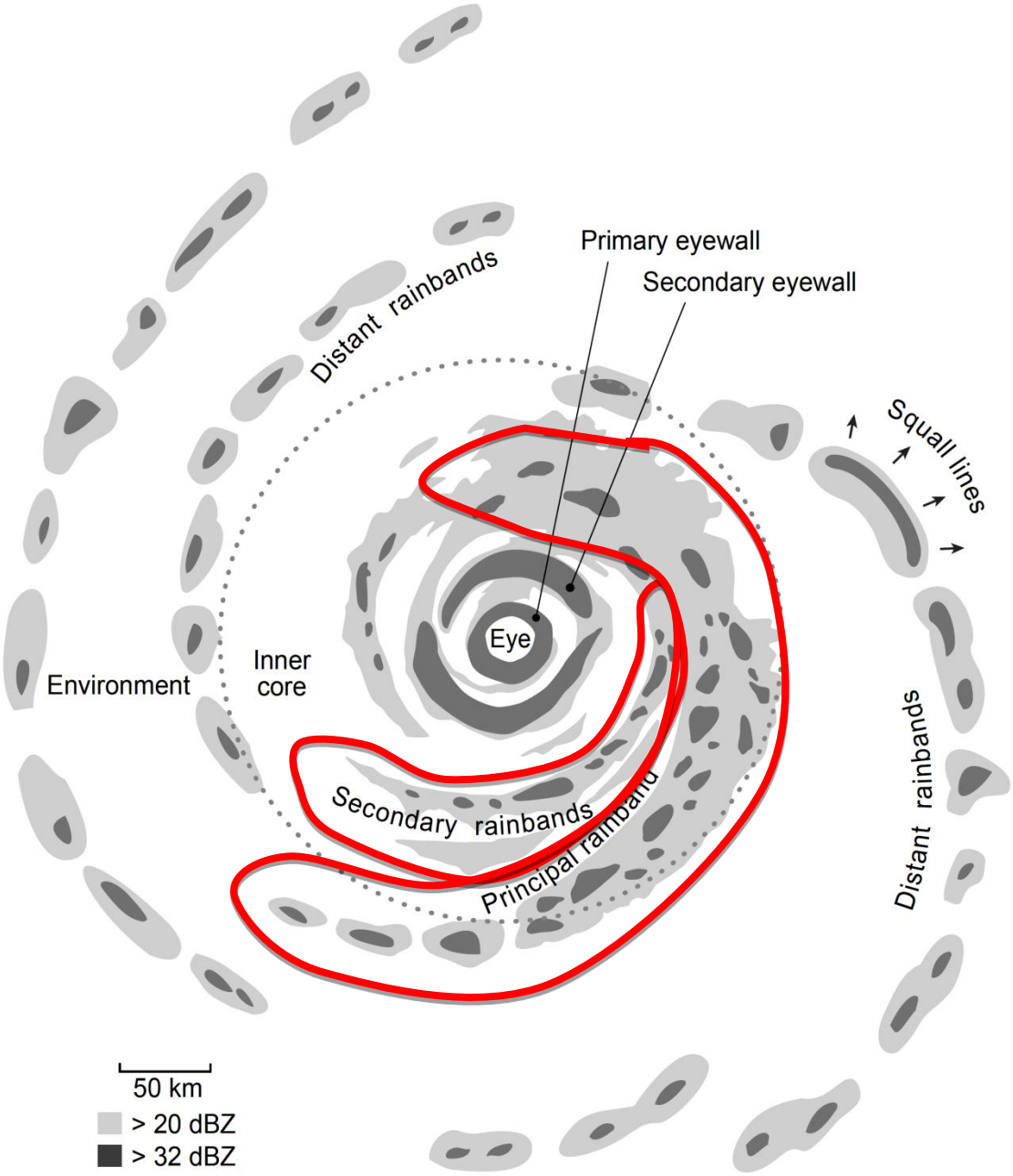
Updrafts
上沖氣流



Downdrafts
下沖氣流



雙眼牆及其替換過程
Double Eyewall & Eyewall Replacement

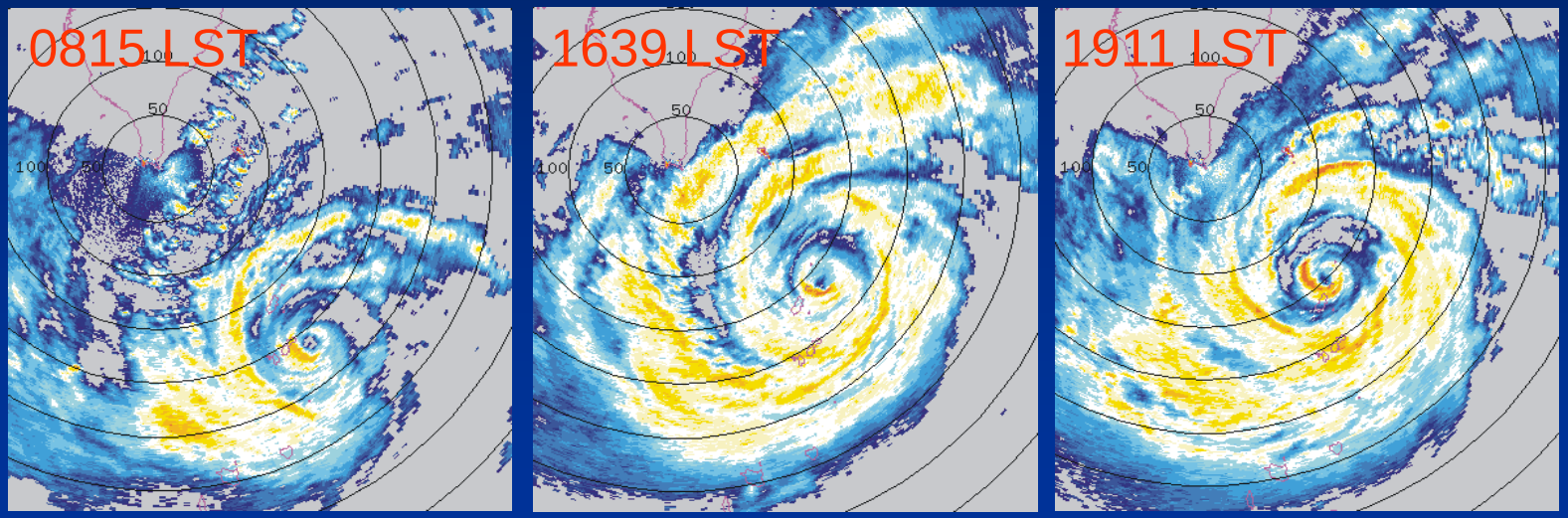


主眼牆
&
次眼牆

Freely adapted from Willoughby 1988

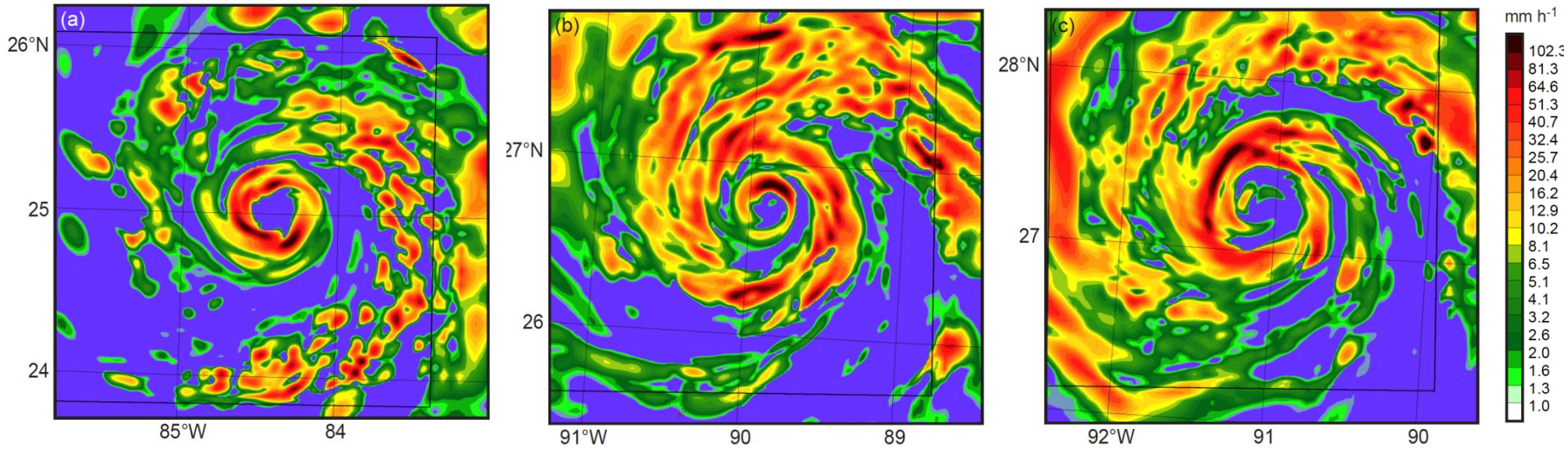
利奇馬(2001)颱風：雙眼牆的形成

墾丁雷達站觀測圖



取自郭鴻基(2004)

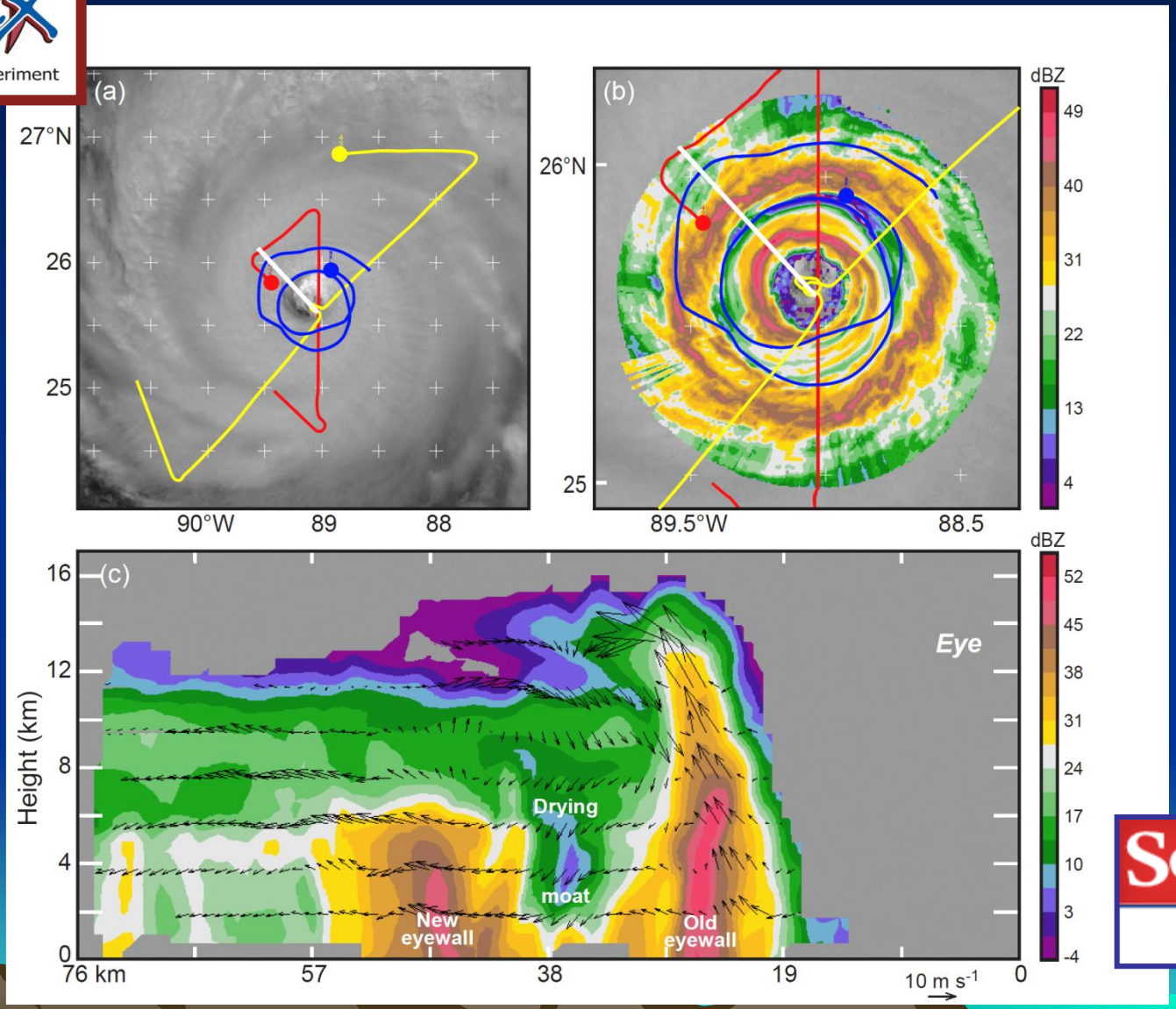
Eyewall Replacement in Rita
Rita(2005)颶風之眼牆替換



MM5 simulation done in the field

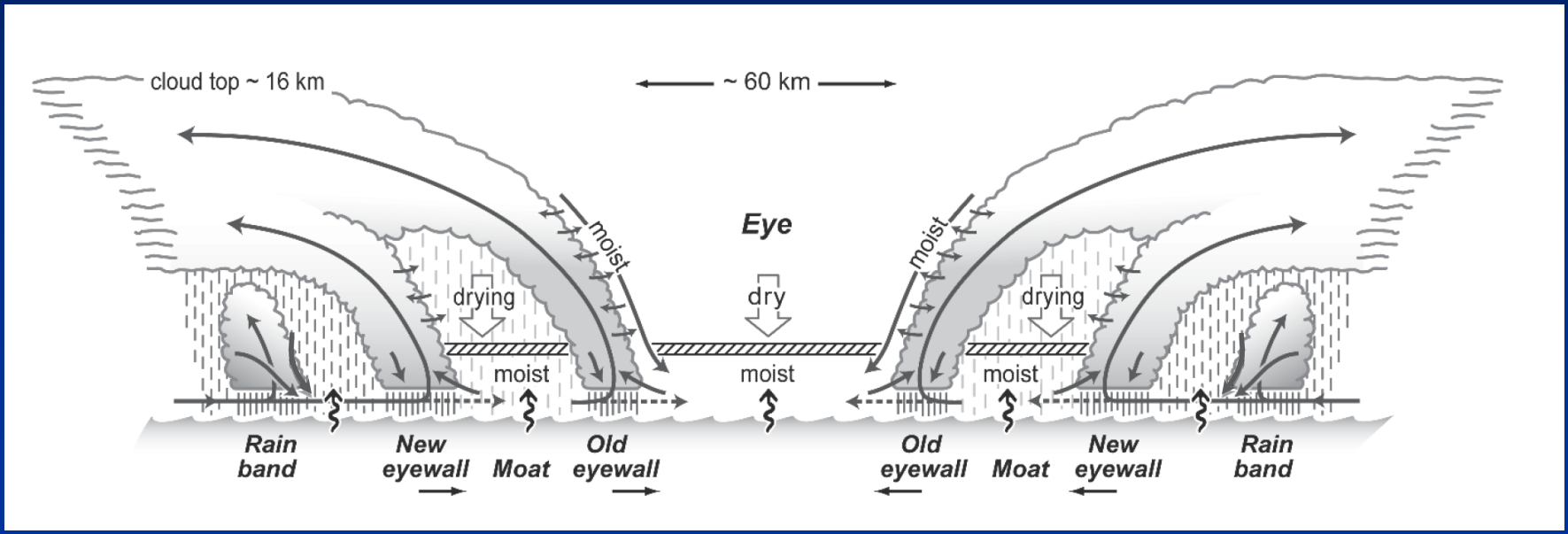
Courtesy Shuyi Chen

Aircraft Flights in Rita



Houze et al. 2007

Double Eyewall Structure Model based on Rita
雙眼牆概念模式



Houze et al. 2007

台灣地形對於颱風路徑的影響

Track discontinuity

Track discontinuity
不連續之颱風路徑

- 王時鼎 (1980): Observation data of 53 typhoons that came close to Taiwan in 1946-1975.

Continuous Track
連續路徑

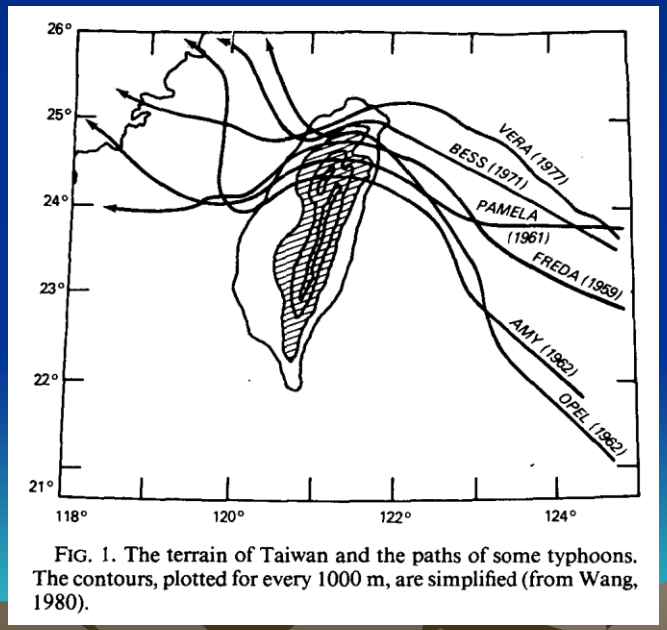


FIG. 1. The terrain of Taiwan and the paths of some typhoons. The contours, plotted for every 1000 m, are simplified (from Wang, 1980).

Discontinuous Track
不連續路徑

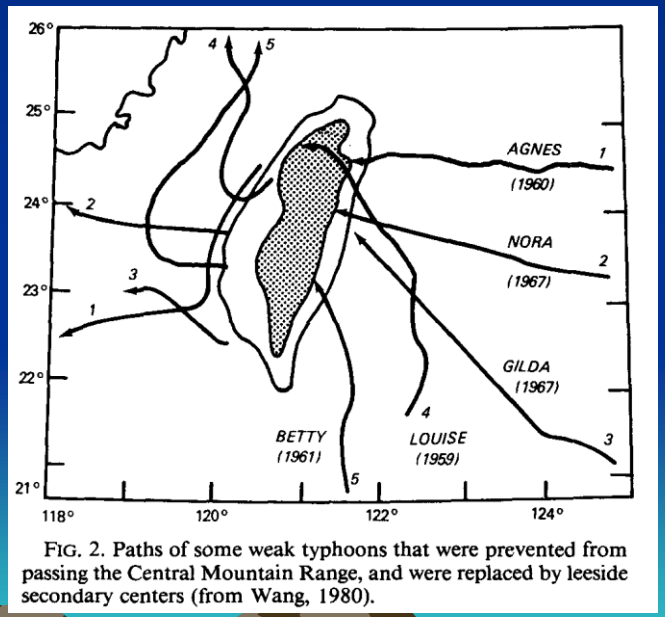


FIG. 2. Paths of some weak typhoons that were prevented from passing the Central Mountain Range, and were replaced by leeside secondary centers (from Wang, 1980).

不連續颱風路徑
——理想化電腦數值模擬

- Chang (1982): The TC is weakened but tends to translate at about twice the speed of the basic flow near the mountain.
- The model TC makes a cyclonic curvature in its path around the northern end of the island mountain.

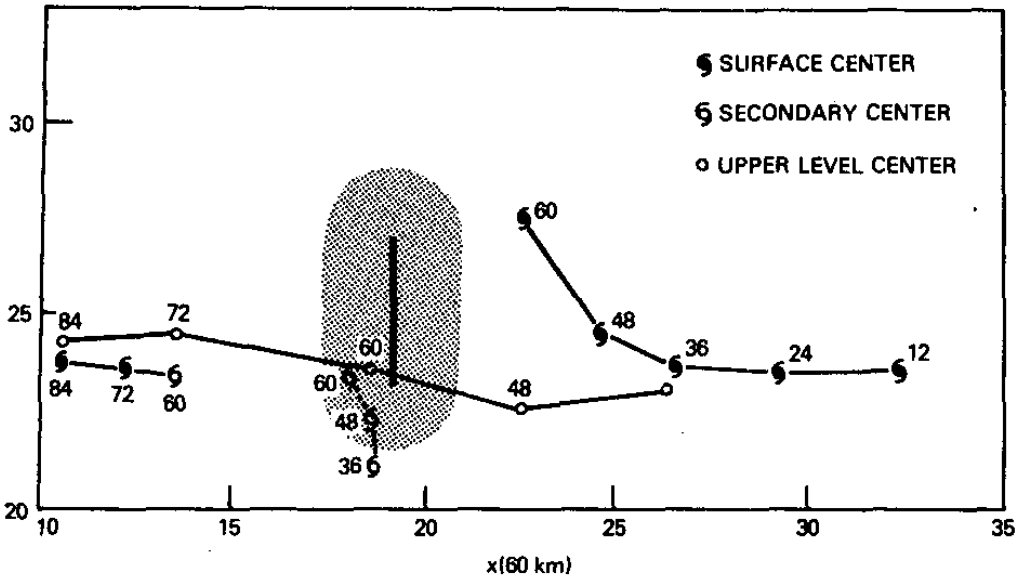


FIG. 12. The movement of the surface and 700 mb centers for Exp. 3. The movements of secondary centers are traced with a dashed line.

不連續颱風路徑
——理想化電腦數值模擬

- Bender et al. (1987): In the case of Taiwan and 10 m/s easterly zonal flow, secondary surface lows develop behind the CMR.

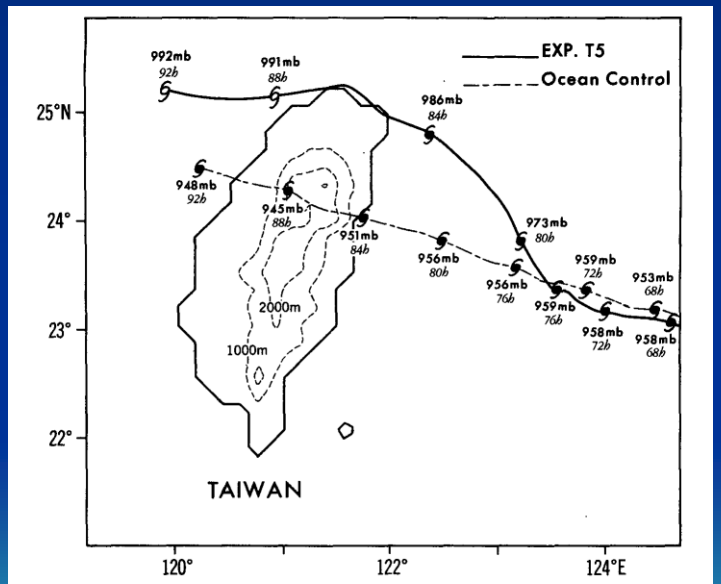


FIG. 6. Storm tracks for Exp. T5 (solid line) and the ocean-only control case (dashed line). The topographical distribution used in Exp. T5 is also shown with the heights contoured at 1000 m intervals. Storm positions are plotted at 4 h intervals. (See Fig. 2 for more details.)

Easterly flow of 10 m/s

不連續颱風路徑
——理想化電腦數值模擬

- Yeh and Elsberry (1993a; MWR)

  ➔Using the NRL model with 45-km horizontal grid size and 16 vertical levels.
- For the westward-moving TCs approaching the southern end of Taiwan island, the mean track deflections are larger.
- For TCs approaching the northern end of Taiwan island, the mean track deflections are smaller.

←

Easterly flow of 5 m/s

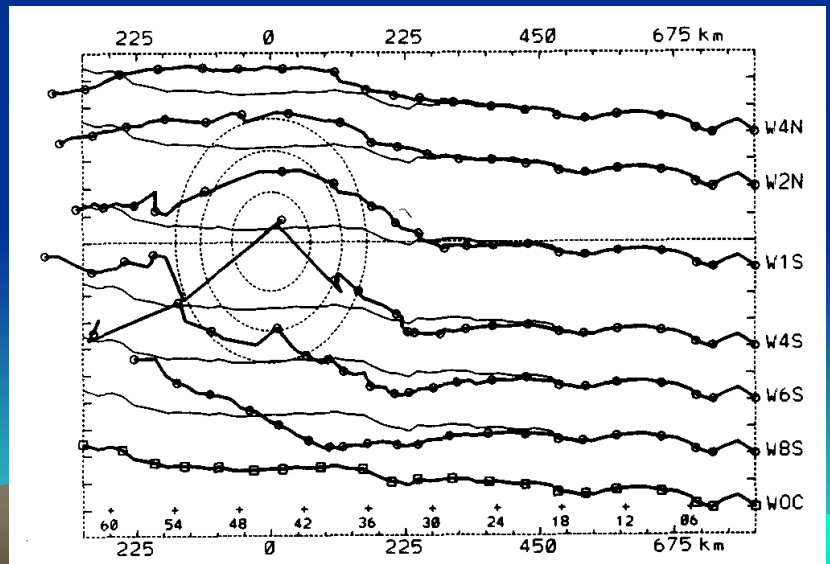
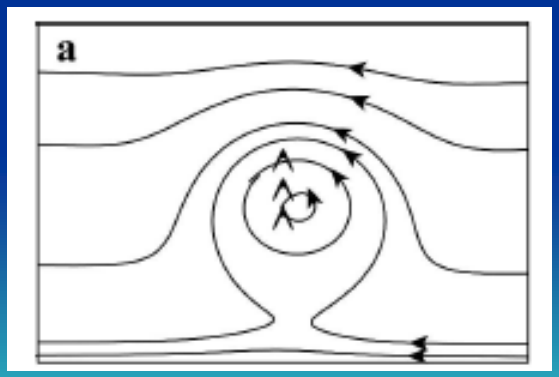


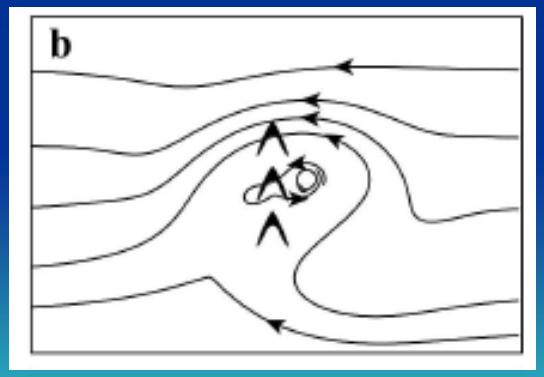
FIG. 12. Tracks as in Fig. 11 of six simulations (lines with circles each 3 h) and the ocean control (line with boxes at bottom and also

不連續颱風路徑
--理想化電腦數值模擬

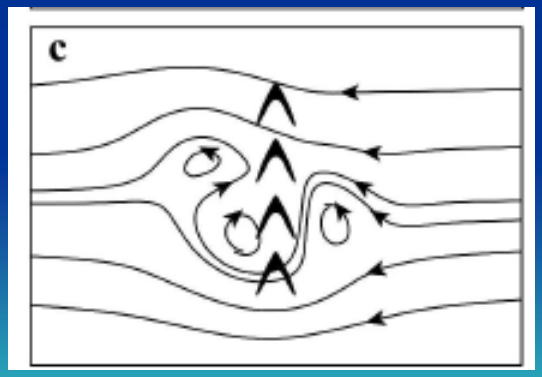
- Lin et al. (2005): With weak orographic blocking, a TC crosses over the mountain range with some northward deflection.
- With moderate orographic blocking, northward deflection is greater upstream of the mountain range and a secondary leeside vortex forms to the southwest of the mountain range.
- With strong orographic blocking, a westward-moving TC is deflected southward and a secondary cyclone forms to the northwest of the mountain range.



輕度阻塞



中度阻塞

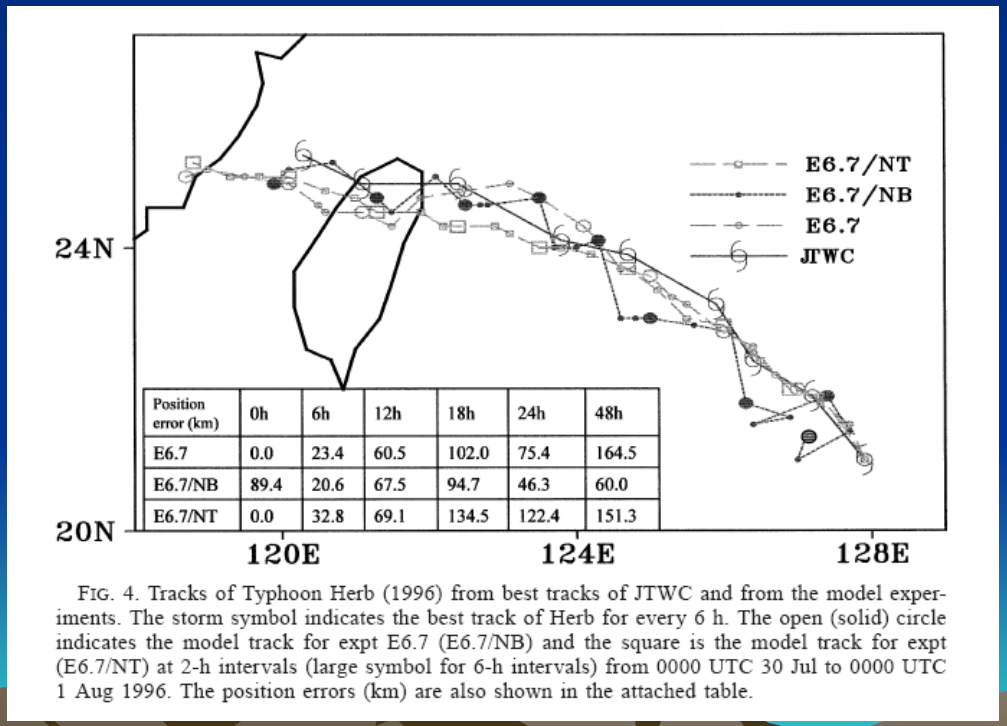


高度阻塞

不連續颱風路徑
--真實個案電腦數值模擬

- Wu et al. (2002; WAF)

  中央山脈的存在僅對賀伯(1996)颱風的路徑有輕微影響



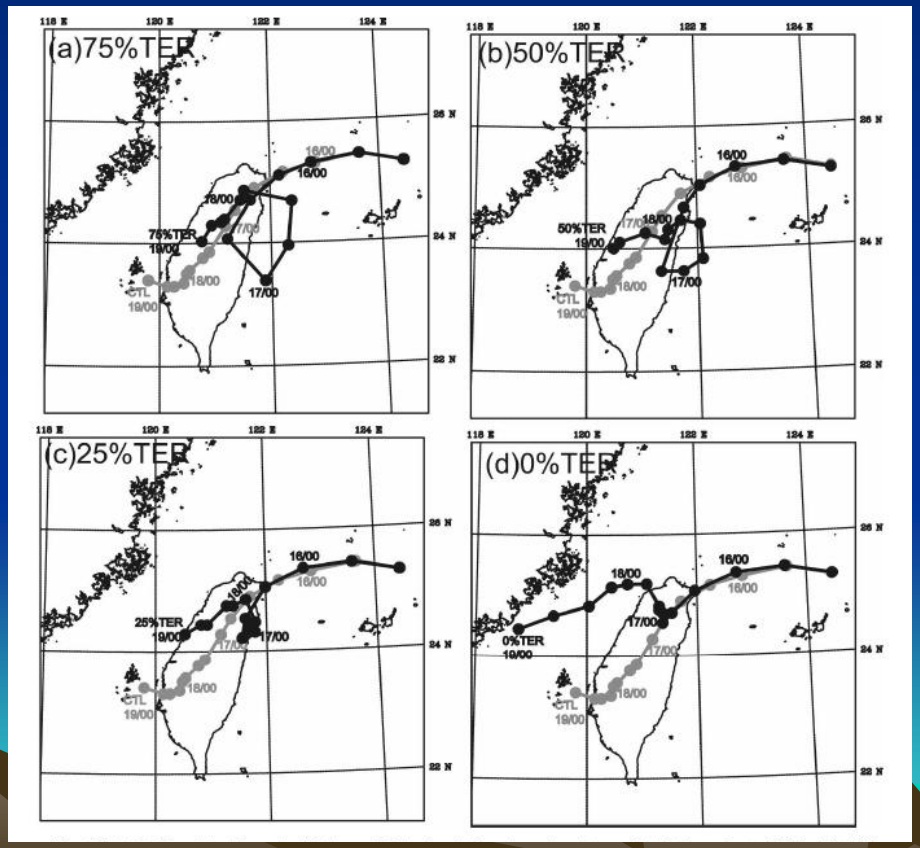
Position error (km)	0h	6h	12h	18h	24h	48h
E6.7	0.0	23.4	60.5	102.0	75.4	164.5
E6.7/NB	89.4	20.6	67.5	94.7	46.3	60.0
E6.7/NT	0.0	32.8	69.1	134.5	122.4	151.3

FIG. 4. Tracks of Typhoon Herb (1996) from best tracks of JTWC and from the model experiments. The storm symbol indicates the best track of Herb for every 6 h. The open (solid) circle indicates the model track for expt E6.7 (E6.7/NB) and the square is the model track for expt (E6.7/NT) at 2-h intervals (large symbol for 6-h intervals) from 0000 UTC 30 Jul to 0000 UTC 1 Aug 1996. The position errors (km) are also shown in the attached table.

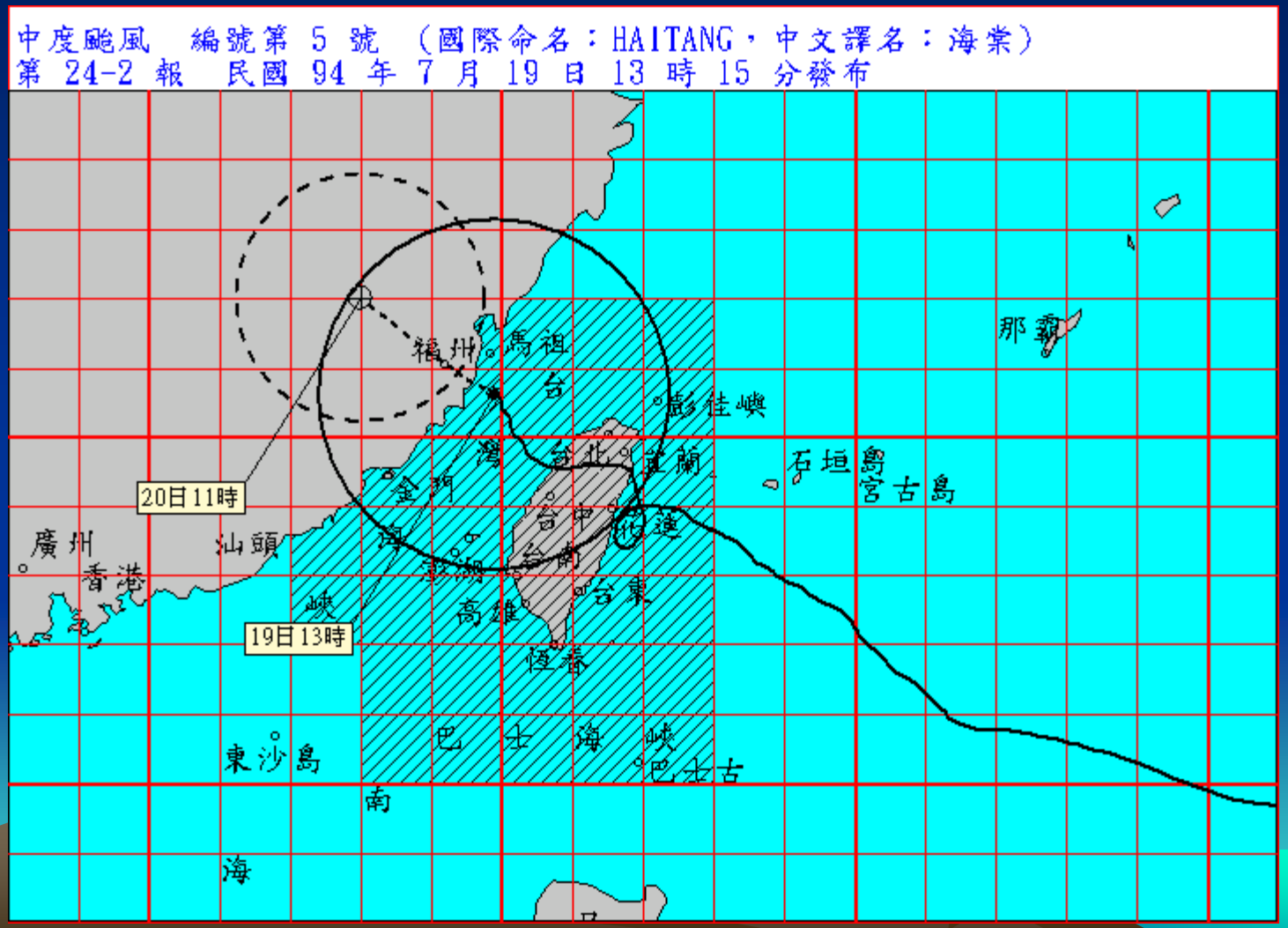
不連續颱風路徑
--真實個案電腦數值模擬

- Yang et al. (2008; JAS)

中央山脈高度對於納莉**(2001)**颱風路徑有重要且非線性的影響



海棠(2005)颱風


中度颱風 編號第 5 號 (國際命名：HAITANG，中文譯名：海棠)
第 24-2 報 民國 94 年 7 月 19 日 13 時 15 分發布
福州
馬祖
澎佳嶼
那覇
石垣島
宮古島
20日11時
廣州
汕頭
香港
19日13時
東沙島

打轉颱風路徑
--海棠個案電腦數值模擬

- Jian and Wu (2008):

➔Enhancement of Haitang's southward deflection before landfall due to channeling effect.

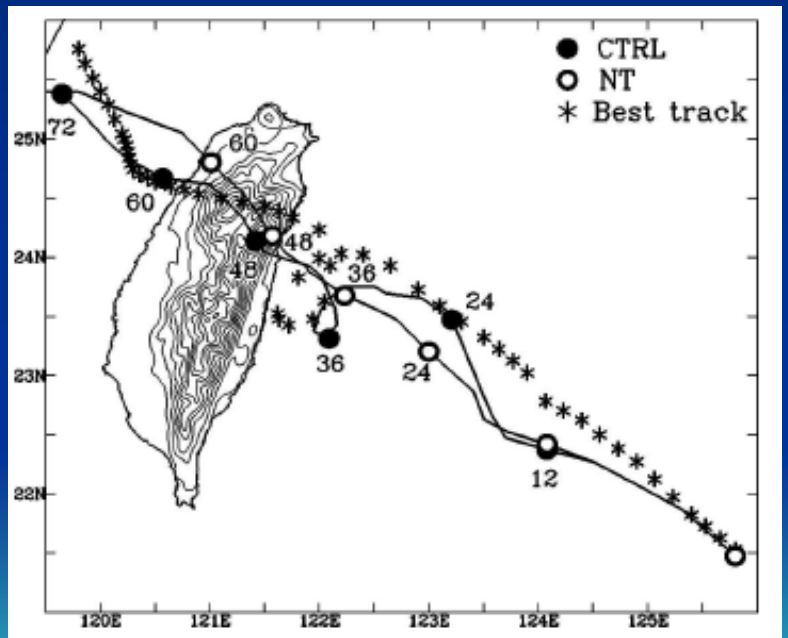


FIG. 4. Simulated tracks in the CTRL (solid circles) and NT (open circles) experiments. The asterisk symbols are the best-track positions every 1 h from 0000 UTC 17 Jul to 0600 UTC 19 Jul. The Taiwan terrain heights (thin lines) in experiment CTRL start from 200 m high and have a contour interval of 300 m. Both of the 72-h model simulations begin at 0000 UTC 17 Jul 2005.

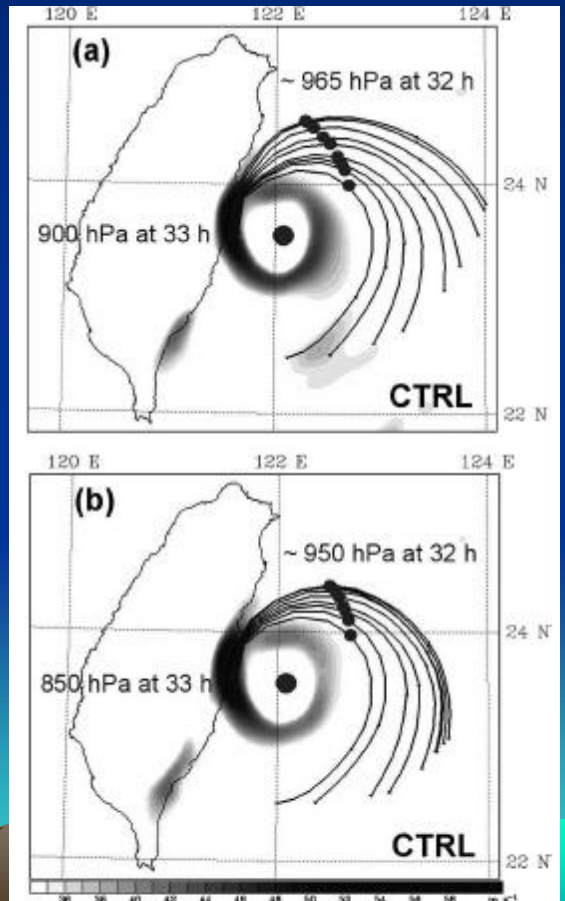


FIG. 7. Backward trajectories based on the WRF-ARW simu-

打轉颱風路徑
——海棠個案電腦數值模擬

- Jian and Wu (2008): Less southward deflection before landfall due to reduced channeling effect in lower terrain heights.

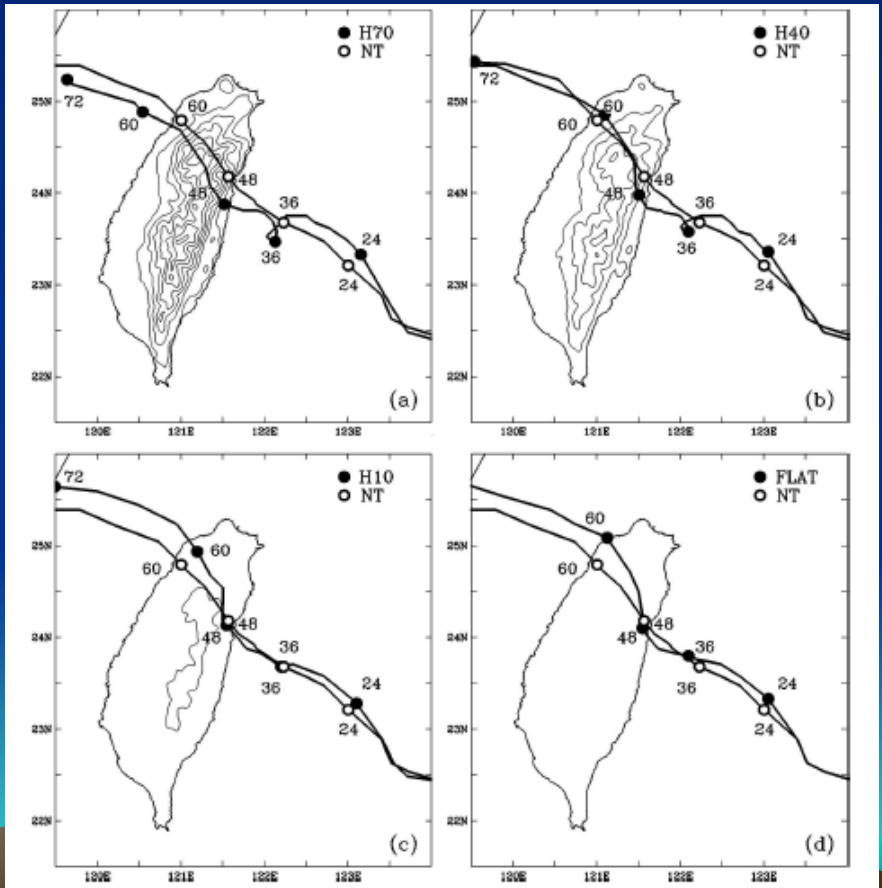
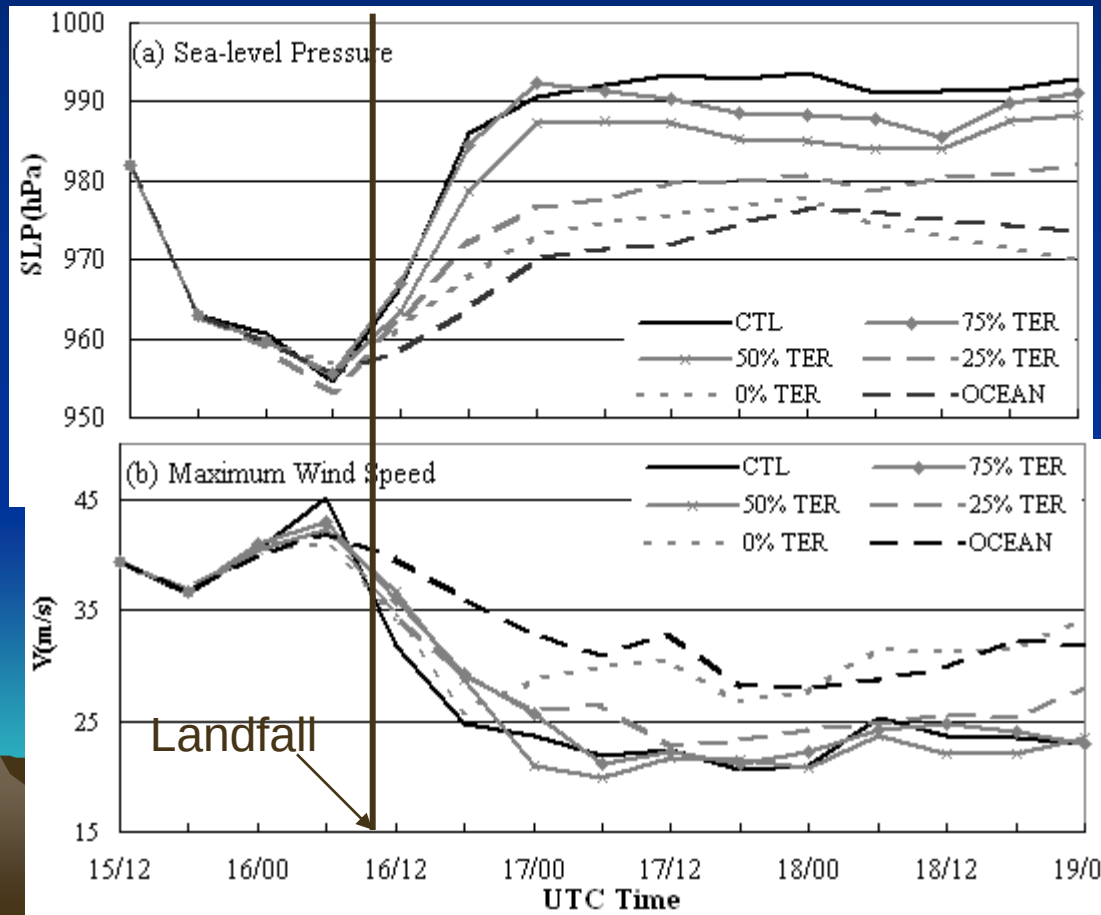


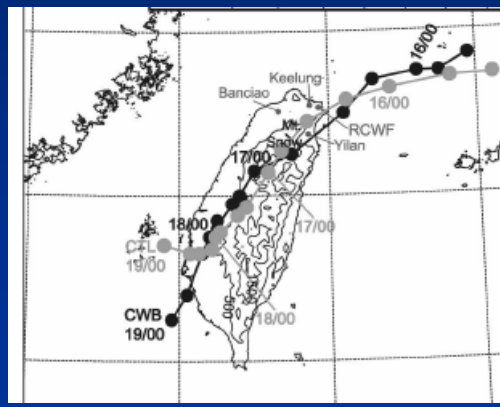
FIG. 9. Comparison of the simulated tracks in the NT experiment (open circles) and the (a) H70, (b) H40, (c) H10, and (d) FLAT experiments (solid circles). The terrain heights (thin lines) in these sensitivity studies start from 200 m high and have a contour interval of 300 m.

台灣地形對於颱風強度的影響
Impact on storm intensity

地形高度對颱風強度之影響
--納莉個案電腦數值模擬

- Yang et al. (2008): 地形高度對於颱風強度之影響為線性的, 即越高的山脈造成颱風強度的減弱情形越大





台灣地形對侵台颱風造成的近地面天氣現象
Impact on surface features

焚風Foehn

- Wu et al. (2002; WAF)
- ➔Extremely dry and warm air on the lee side due to adiabatic warming during Typhoon Herb (1996)

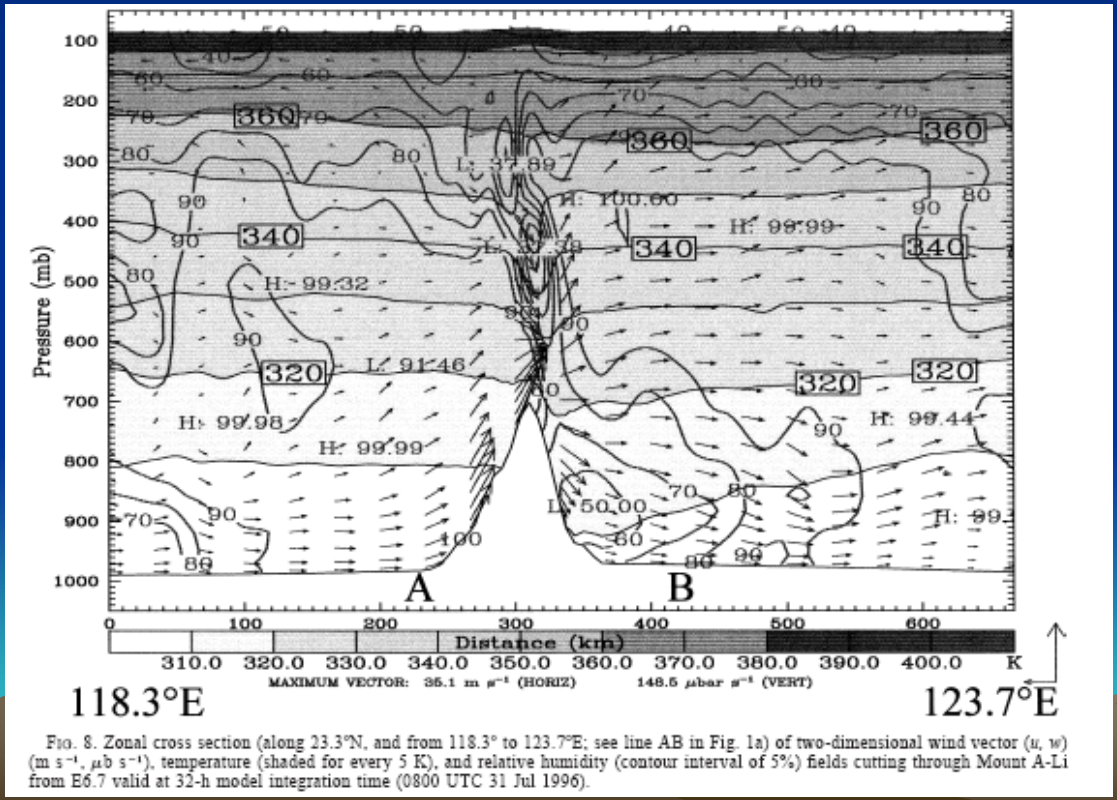
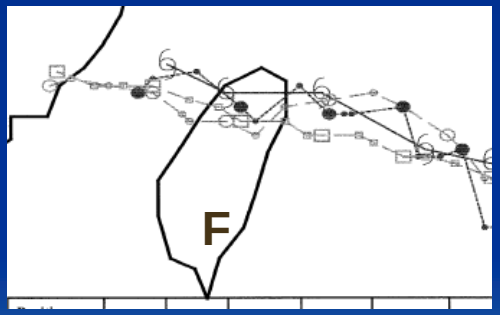


FIG. 8. Zonal cross section (along 23.3°N, and from 118.3° to 123.7°E; see line AB in Fig. 1a) of two-dimensional wind vector (u, w) (m s^{-1}, μb s^{-1}), temperature (shaded for every 5 K), and relative humidity (contour interval of 5%) fields cutting through Mount A-Li from E6.7 valid at 32-h model integration time (0800 UTC 31 Jul 1996).



副低壓Secondary low

- 王時鼎 (1980): Surface pressure and flow pattern associated with typhoons (continuous and discontinuous tracks)

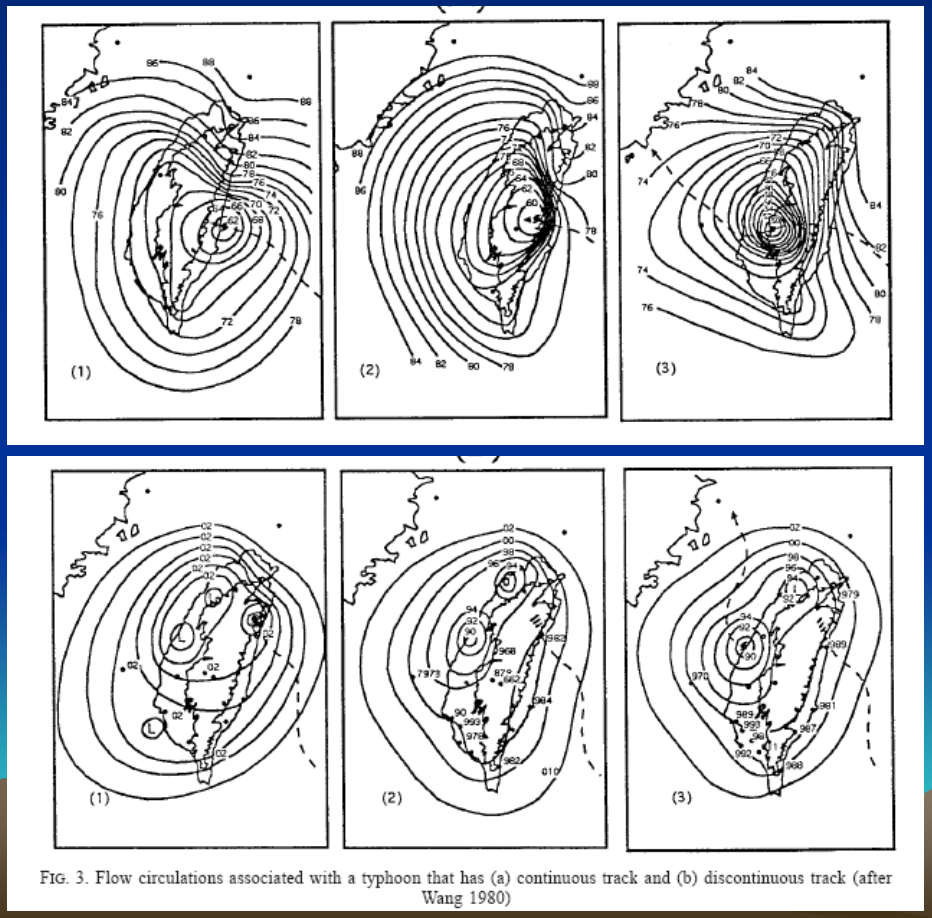


FIG. 3. Flow circulations associated with a typhoon that has (a) continuous track and (b) discontinuous track (after Wang 1980)

Continuous TC tracks
連續性颱風路徑

Discontinuous TC tracks
不連續性颱風路徑

台灣地形對於侵台颱風降雨之影響
Impact on rainfall

地形解析度 vs.電腦模式解析度

- Wu et al. (2002):

➔Central Mountain Range plays a key role in increasing total rainfalls of Typhoon Herb (1996) on Taiwan.

➔ 地形解析度與模式解析度對於賀伯(1996)颱風登陸期間阿里山區豪雨的產生扮演相同重要的角色

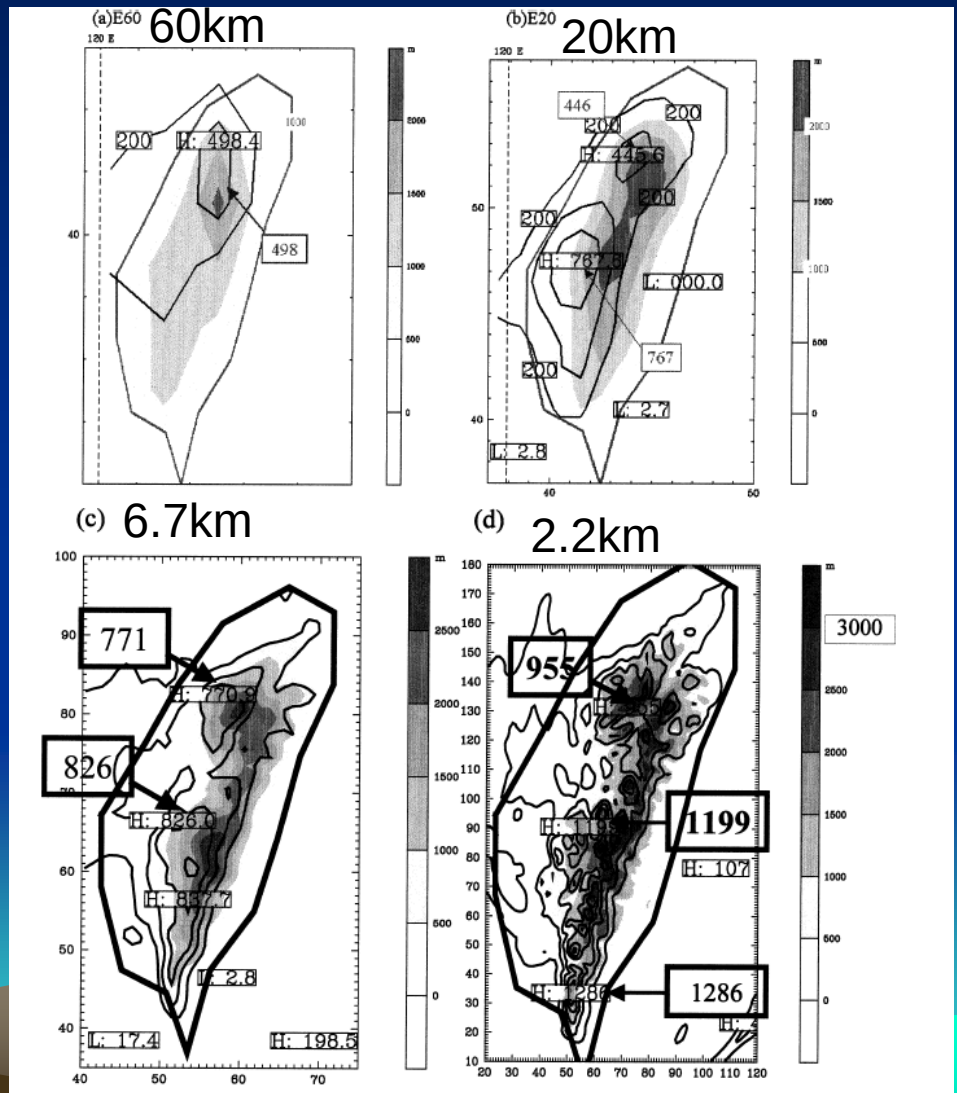


FIG. 6. The 24-h rainfall (with a contour interval of 200 mm) ending at 0000 UTC 1 Aug 1996 from simulations with the highest horizontal grid spacings of (a) 60, (b) 20, (c) 6.7, and (d) 2.2 km. Corresponding model terrains (m) are shown in shading for every 500 m.

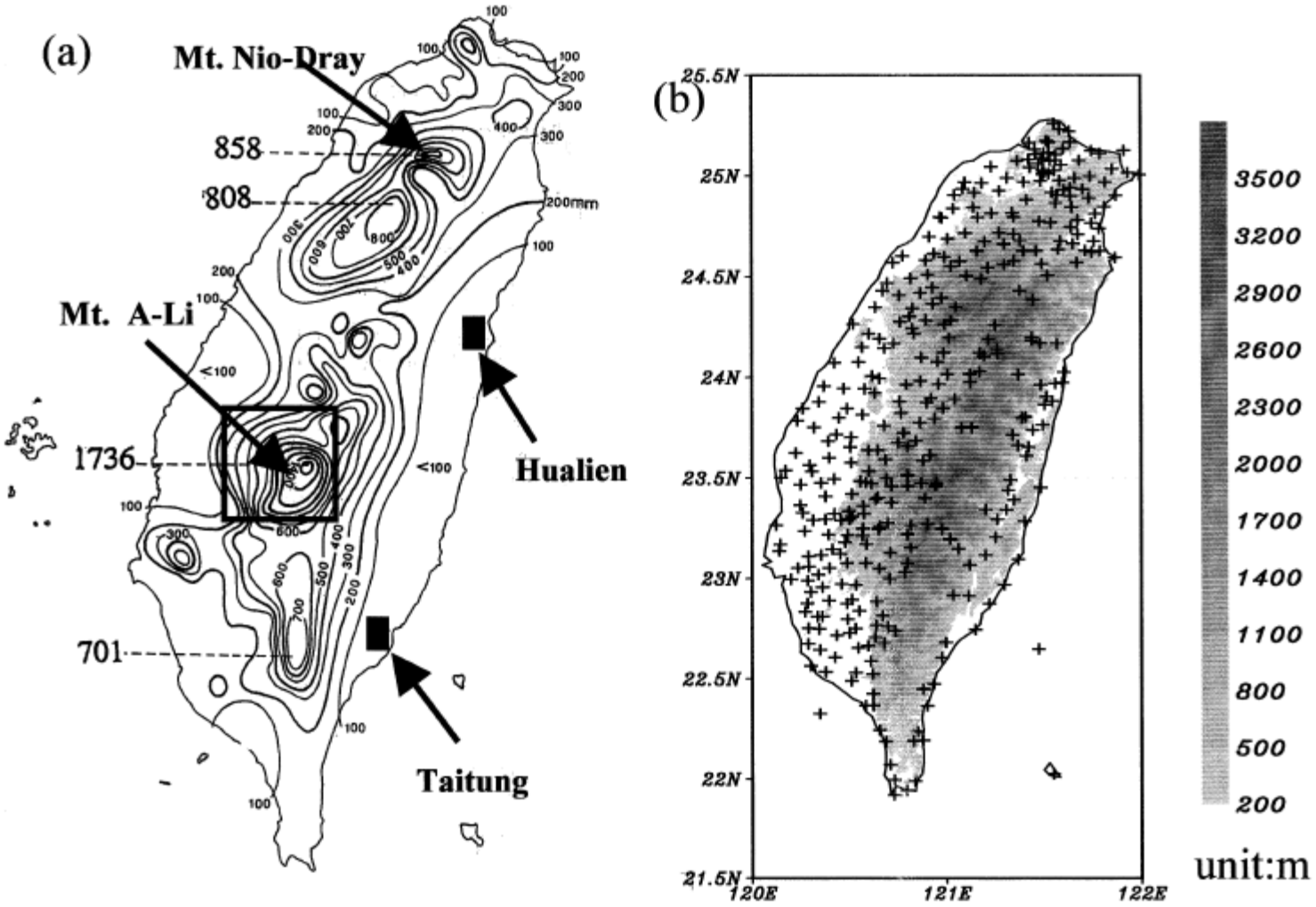


FIG. 1. (a) The 24-h (0000 UTC 31 Jul–0000 UTC 1 Aug 1996) accumulated rainfall (contour interval of 100 mm) during passage of Typhoon Herb (after Shieh et al. 1997). The thickened square box indicates the region (23.3°–23.7°N, 120.6°–121.0°E) for the area average used in Figs. 12, 13, and 15 and Tables 2 and 3. Line AB (along 23.3°N, and from 120° to 122°E) is used for cross-sectional analyses in Figs. 7 and 9. (b) Taiwan terrain shown in shading. The plus signs indicate the locations of the 327 rain gauge stations whose rainfall data are used to plot the rainfall distribution in (a).

取自 Wu et al. (2002)

地形所增加之颱風降雨

- Yang et al. (2008):

➔就納莉(2001)颱風而言，山脈越高，因地形增加之颱風降雨越多.

TABLE 5. The percentage of the island-averaged 24-h accumulated rainfall on 16 Sep 2001 from each 6-km sensitivity experiment with respect to the control simulation.

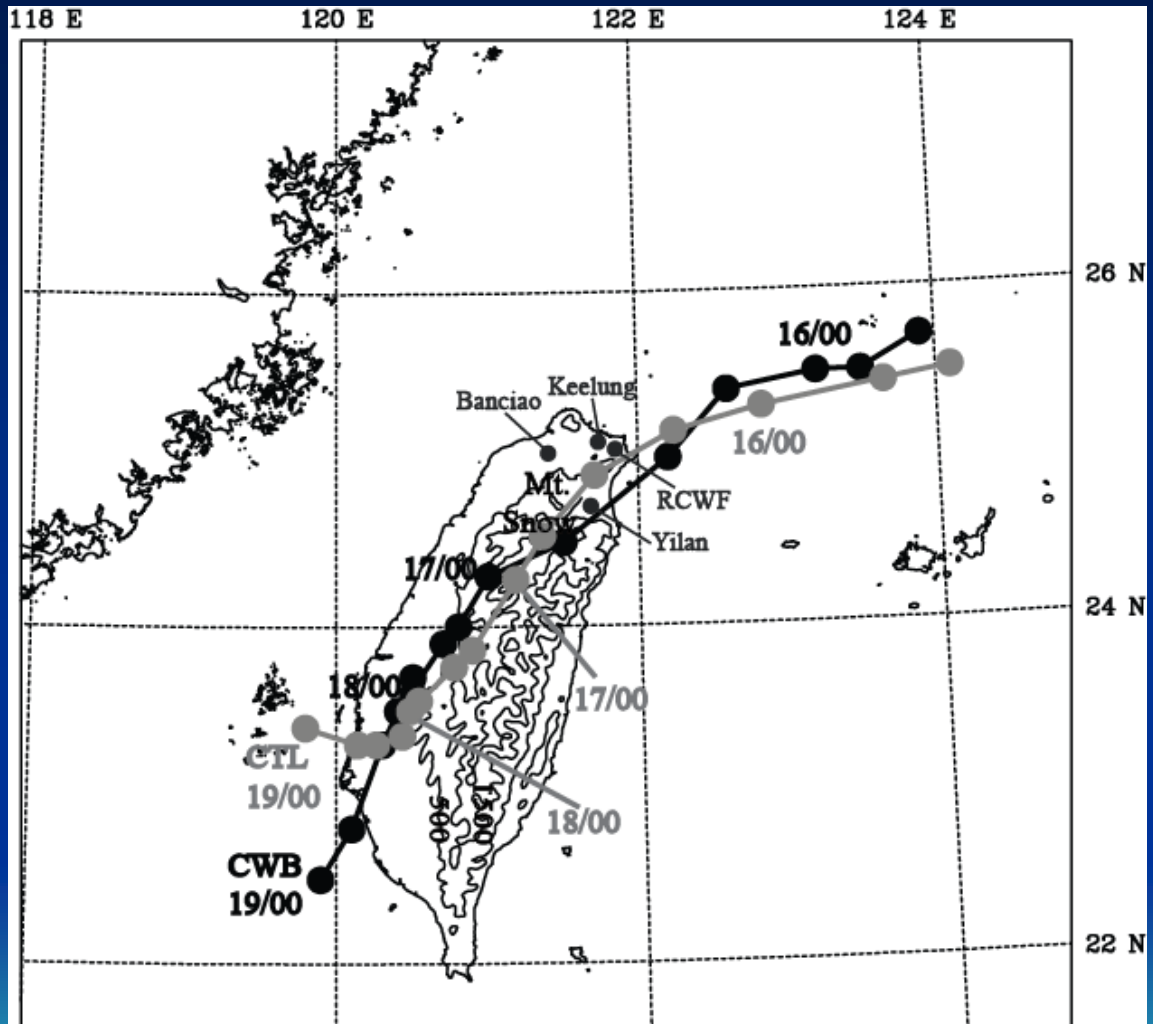
Variable	CTL	75%TER	50%TER	25%TER	0%TER	Ocean
Percentage wrt CTL (%)	100.0	102.9	88.2	70.0	51.9	52.3

TABLE 6. The percentage of the area-averaged 24-h accumulated rainfall within 100-, 150-, and 200-km radii from the typhoon center on 16 Sep 2001 from each 6-km sensitivity experiment with respect to the control simulation.

Radius	No. of points	CTL	75%TER	50%TER	25%TER	0%TER	Ocean
100 km	877	100	97.3	84.2	64.7	62.2	61.5
150 km	1961	100	94.1	85.1	68.5	64.9	64.1
200 km	3503	100	95.4	84.0	71.8	66.3	68.3

台灣地形對於颱風結構的影響
--- 以納莉(2001)颱風為例
Storm’s structure changes during landfall
--- Typhoon Nari (2001) as an example

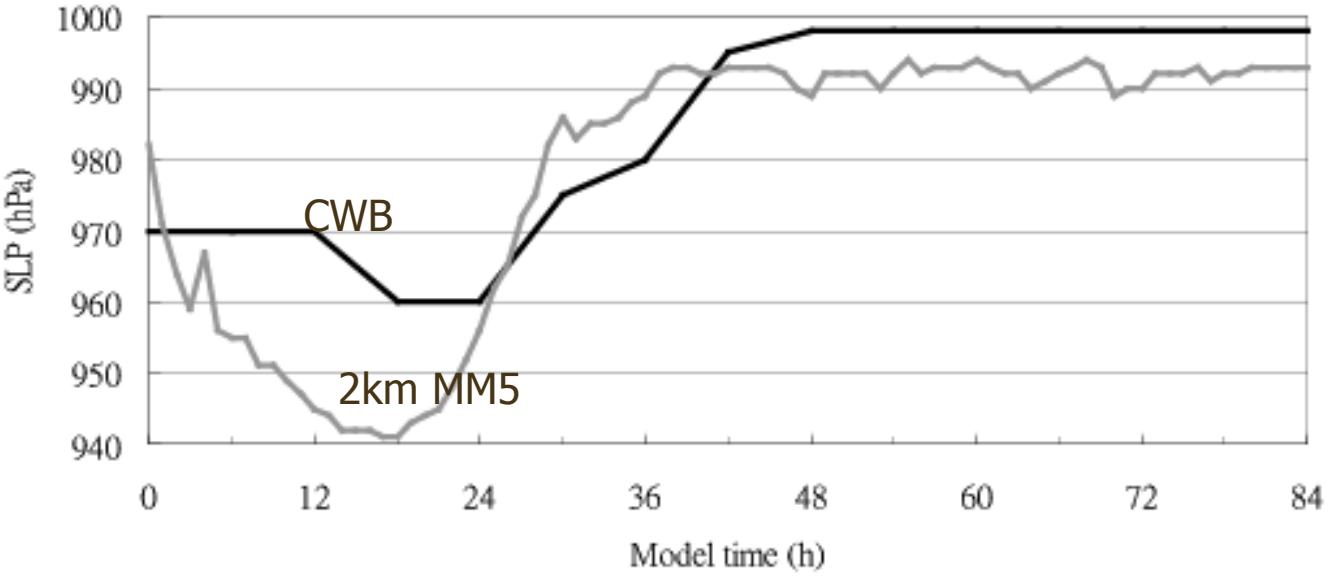
觀測路徑(黑色)與模擬路徑(灰色)之比較

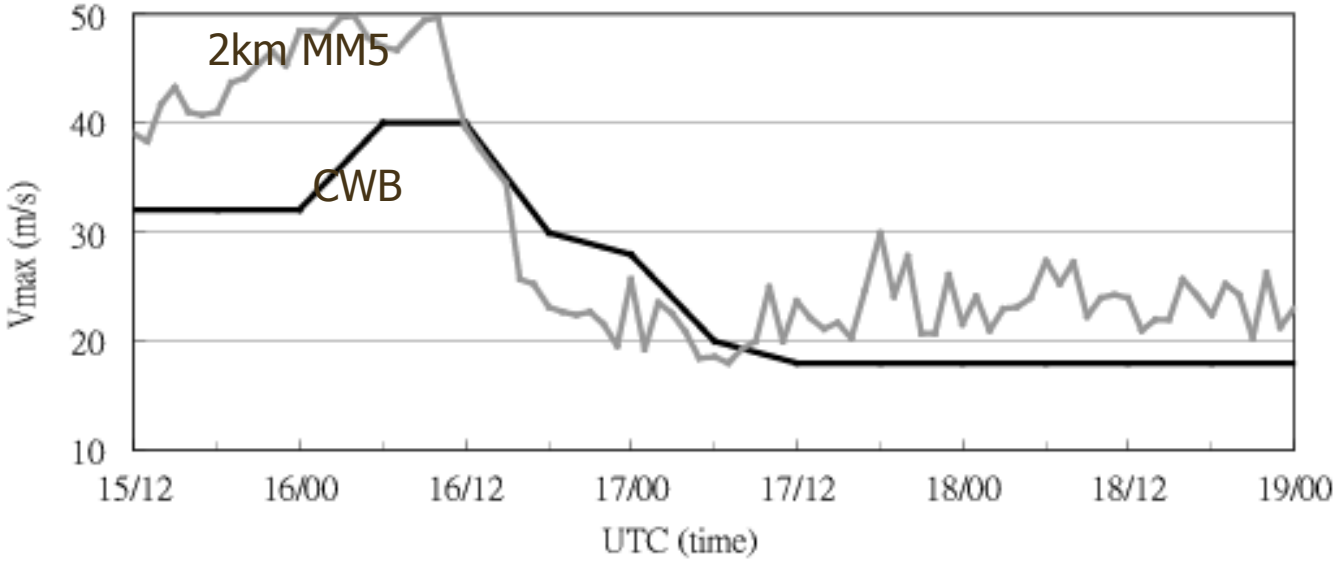


Yang et al. (2008; JAS)

Simulation time (hr)	12	24	36	48	60	72	84
Track error (km)	43.3	61.2	26.8	13.4	12	8.5	104.8

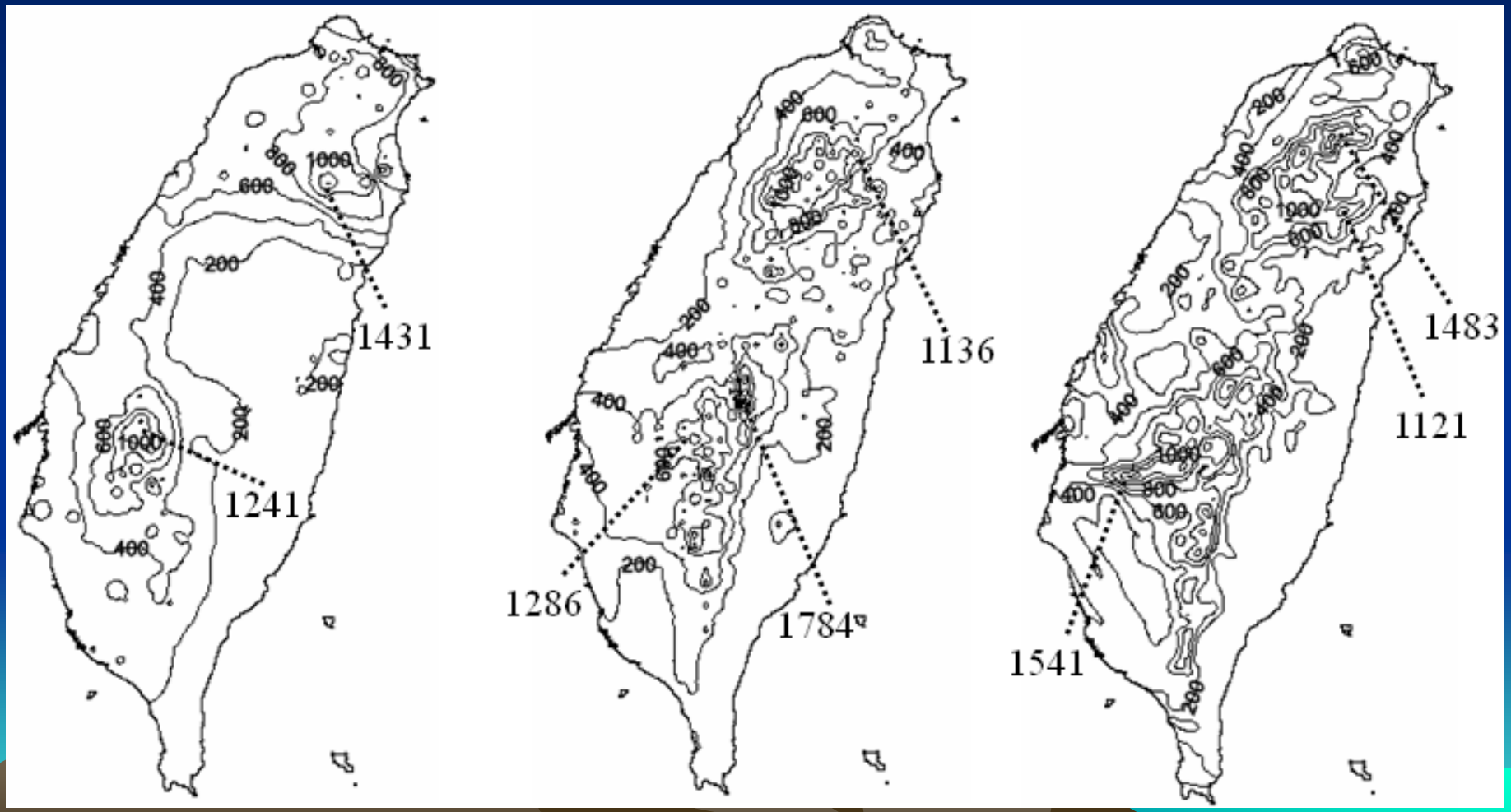
中心最低氣壓及最大風速之時間序列





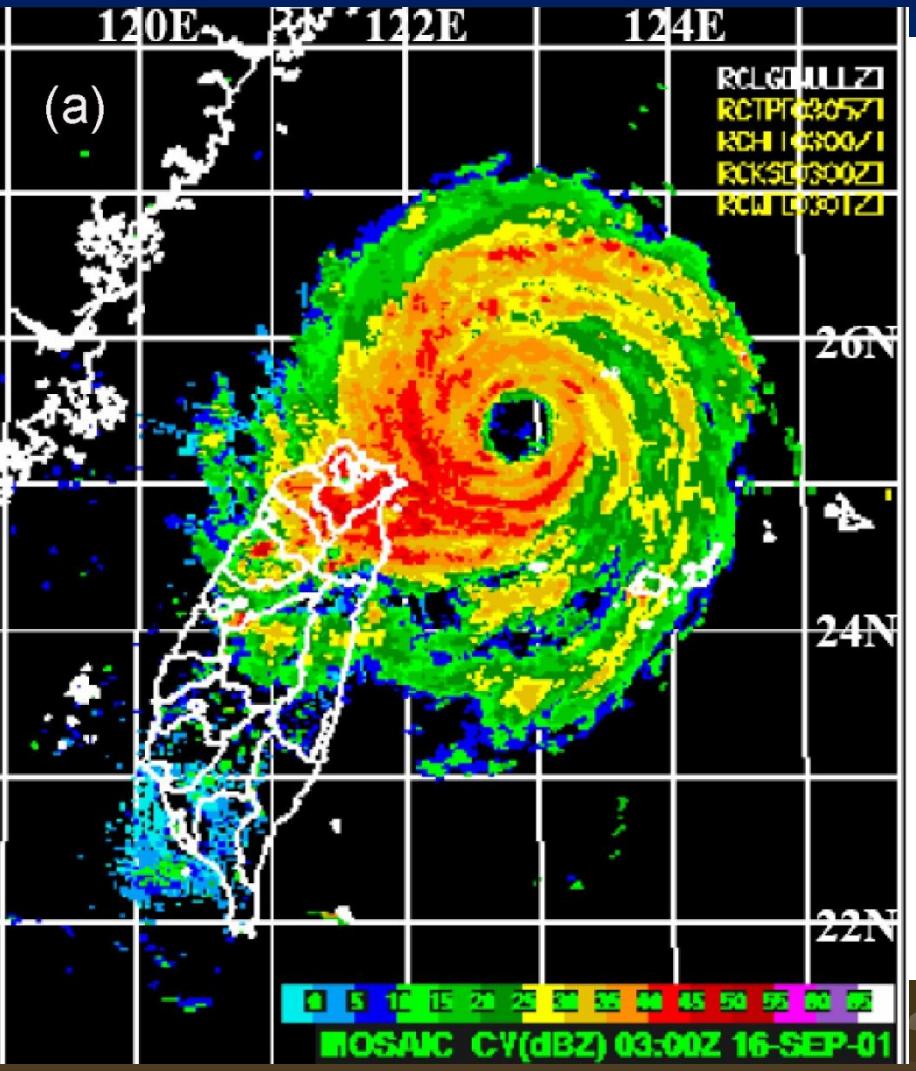
3-day rainfall (09/16~09/18)

OBS 觀測　　6-km MM5電腦模擬　　2-km MM5電腦模擬

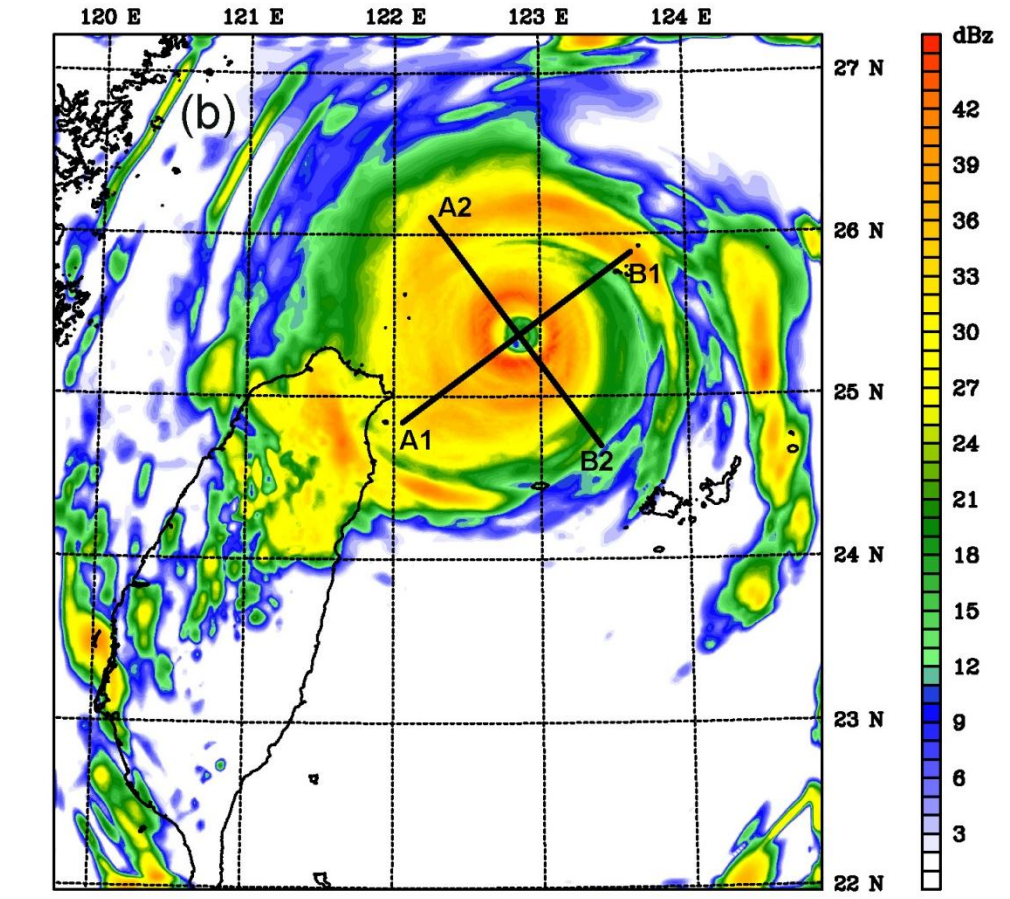


登陸前之雷達回波比較

OBS 觀測



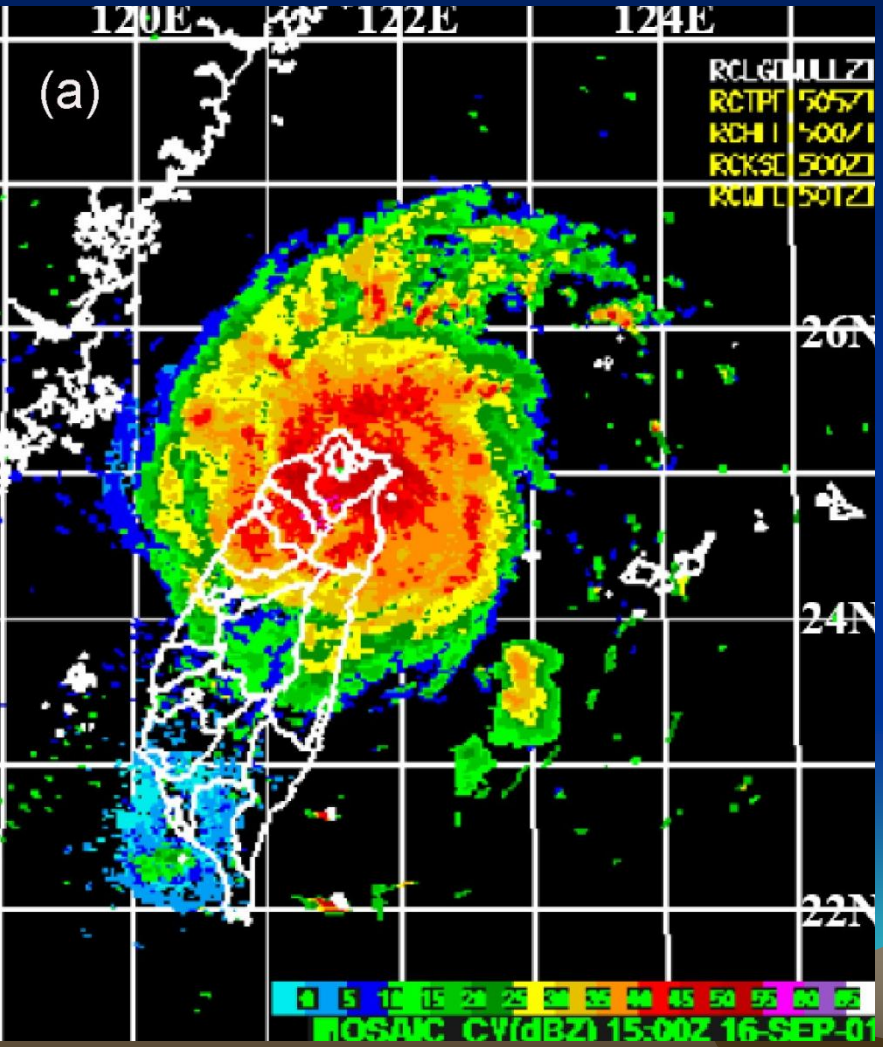
2-km MM5 電腦模擬



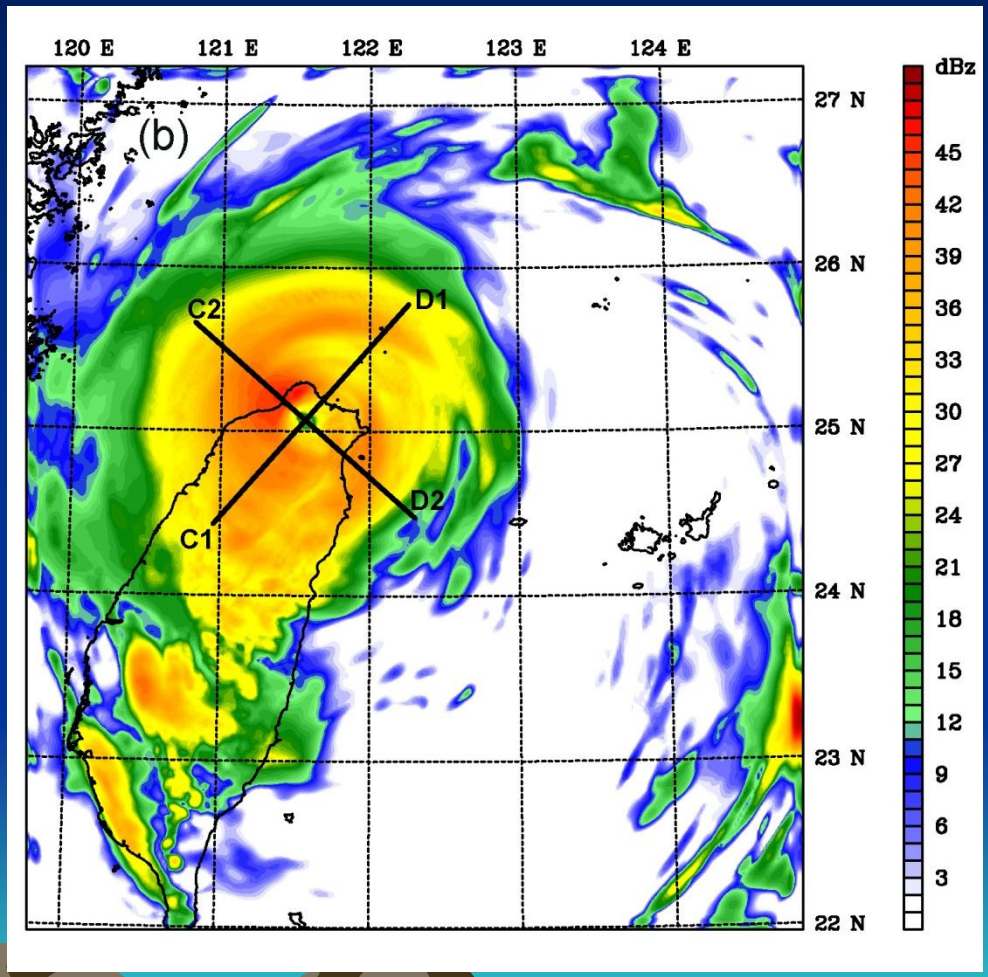
MM5 Radar CV @ 9/16 0130Z
(1-h time averaged)

登陸後之雷達回波比較

OBS 觀測

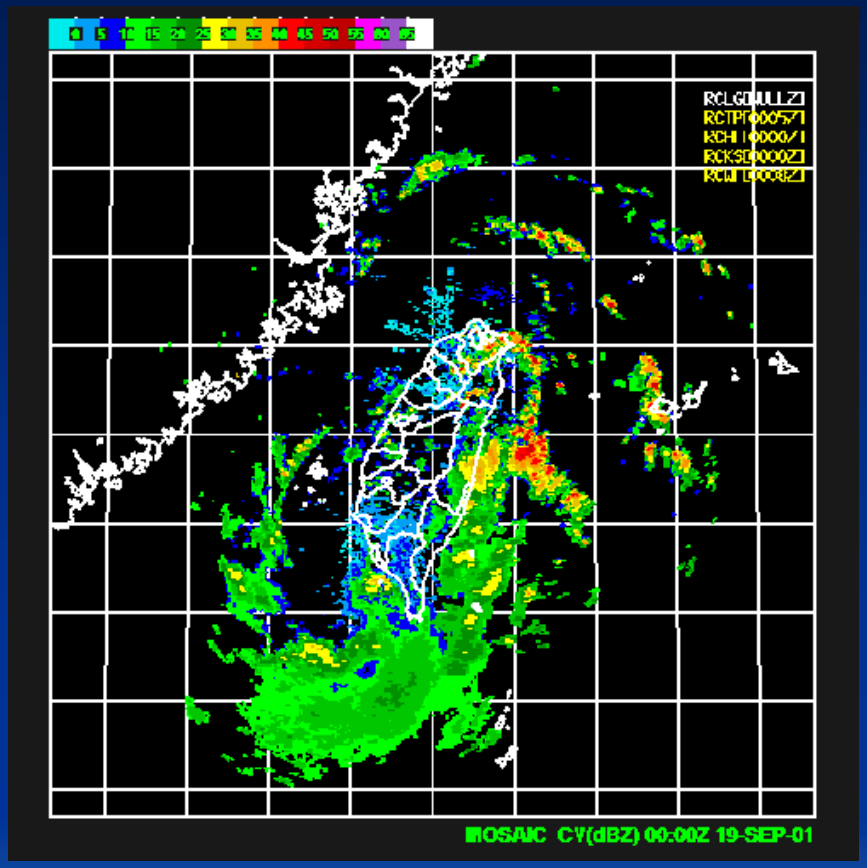


2-km MM5 電腦模擬

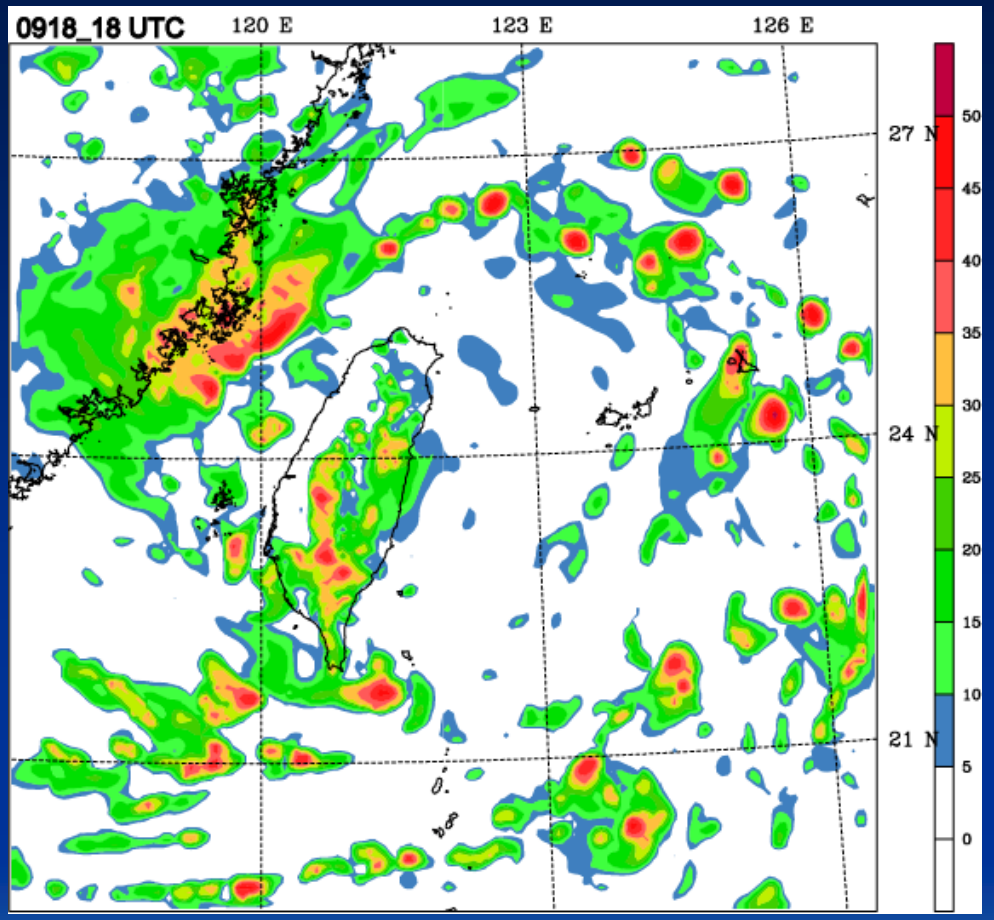


MM5 Radar CV @ 9/16 1200Z
(1-h time averaged)

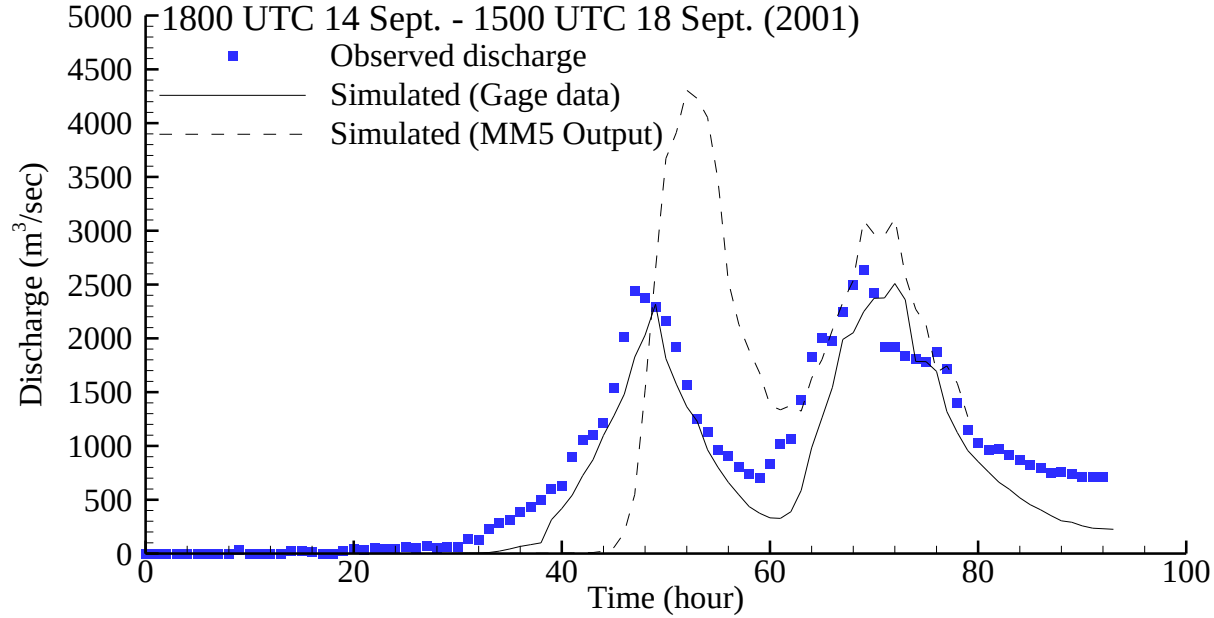
雷達回波觀測



電腦模擬雷達回波

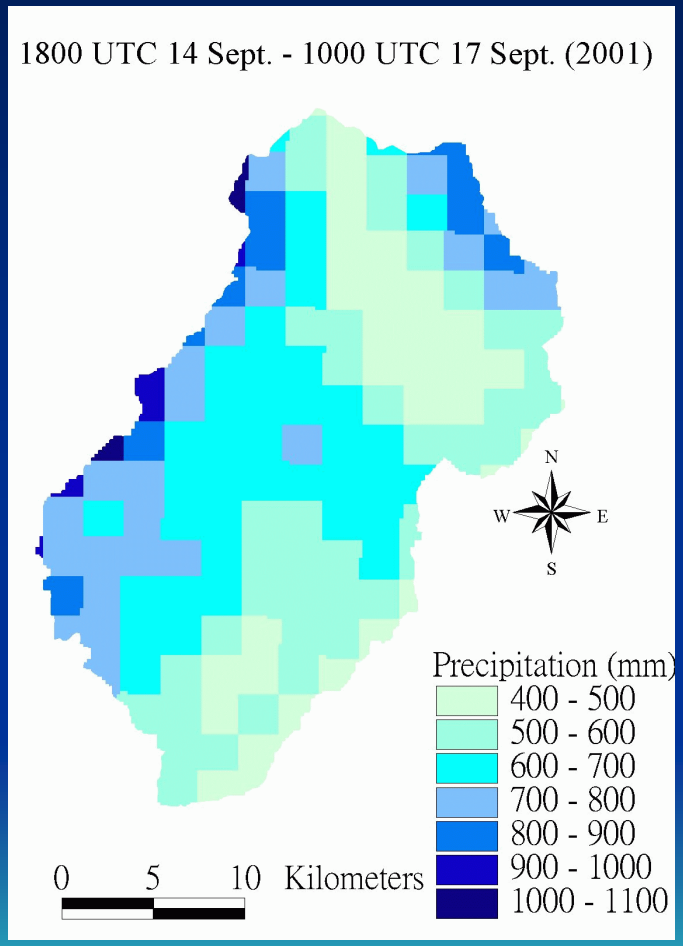


納莉颱風期間大漢溪流量模擬

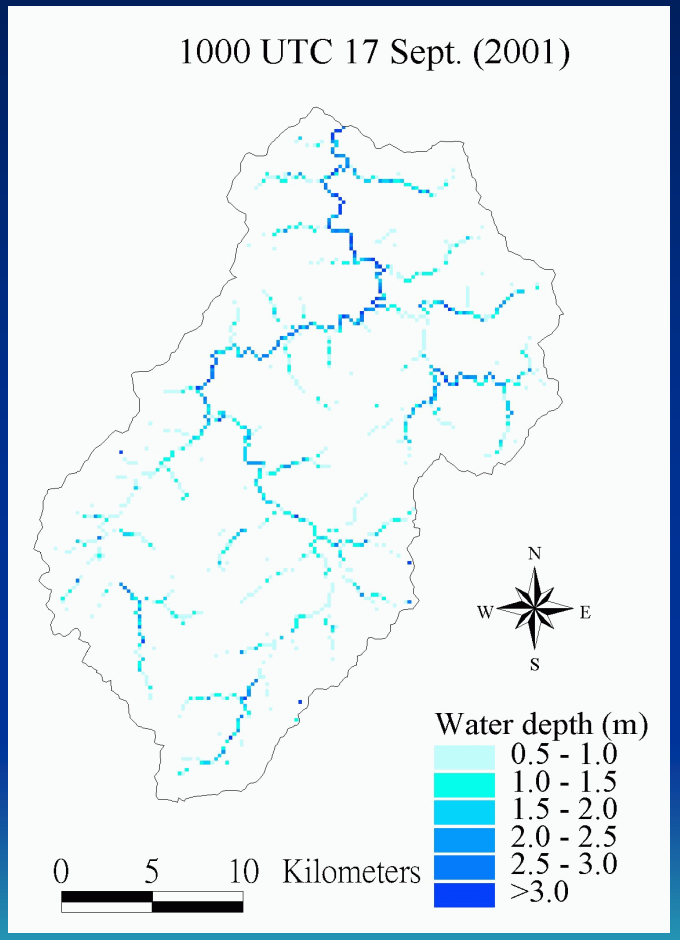


取自李明旭,楊明仁等人(2005)

納莉颱風期間石門水庫流域水文模擬



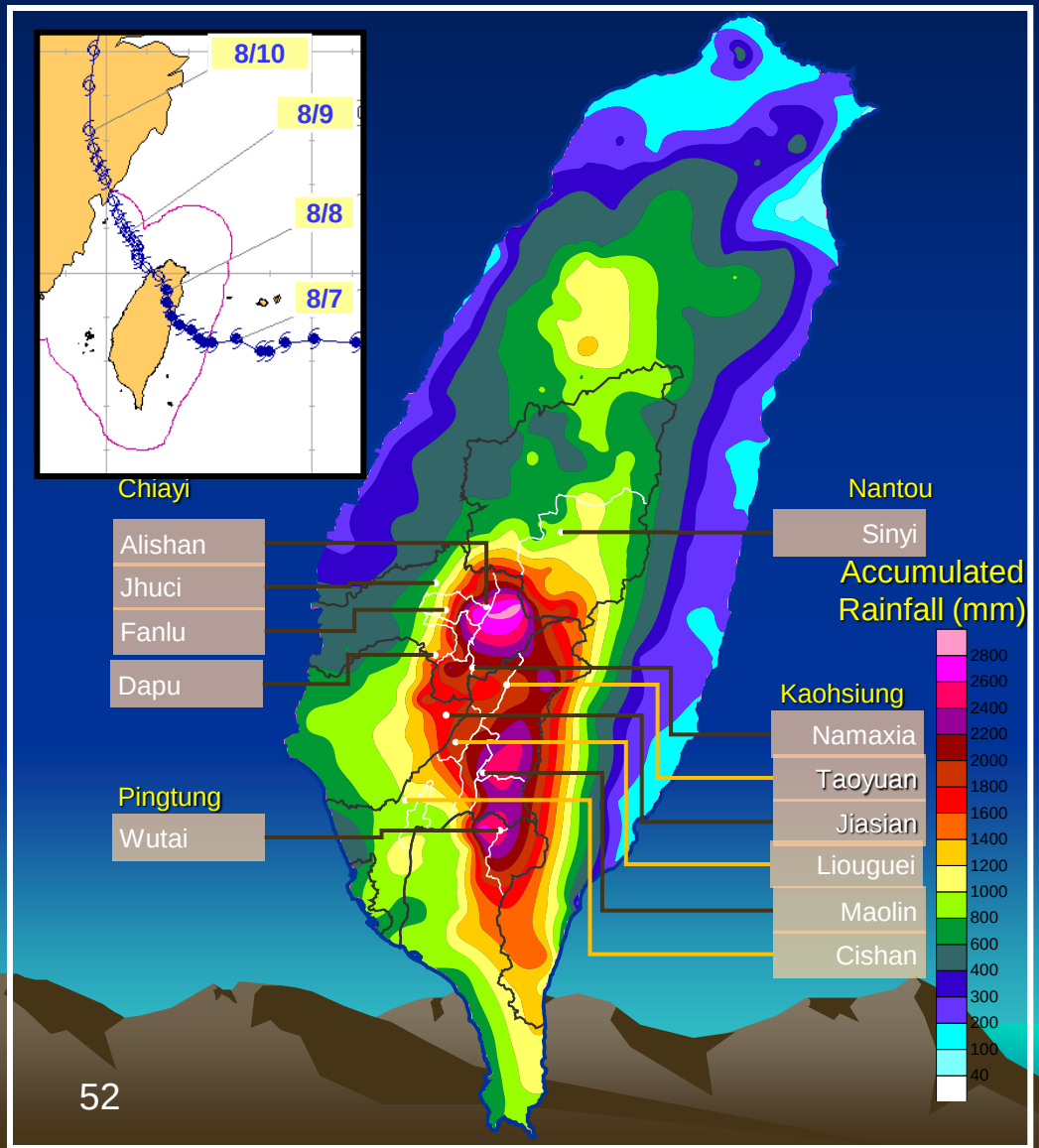
累積雨量模擬



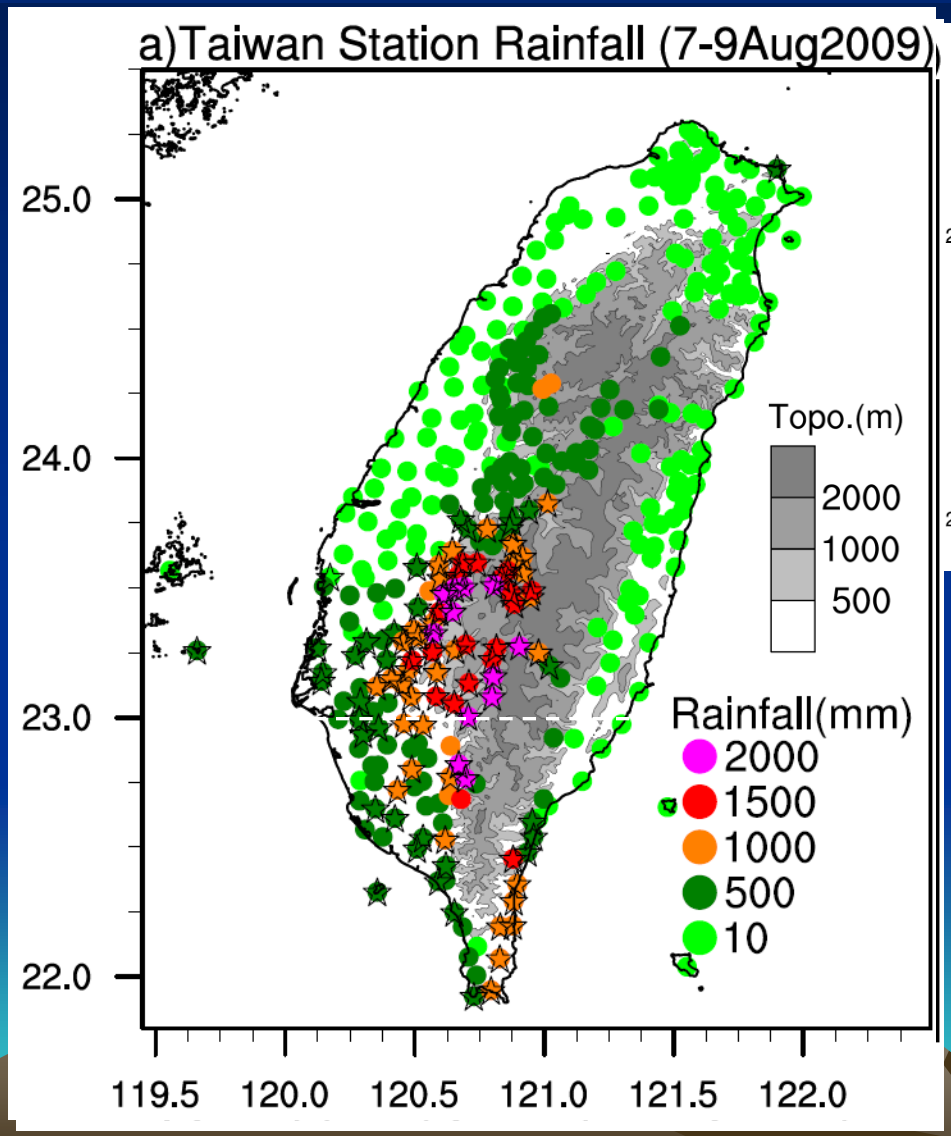
河川水位模擬

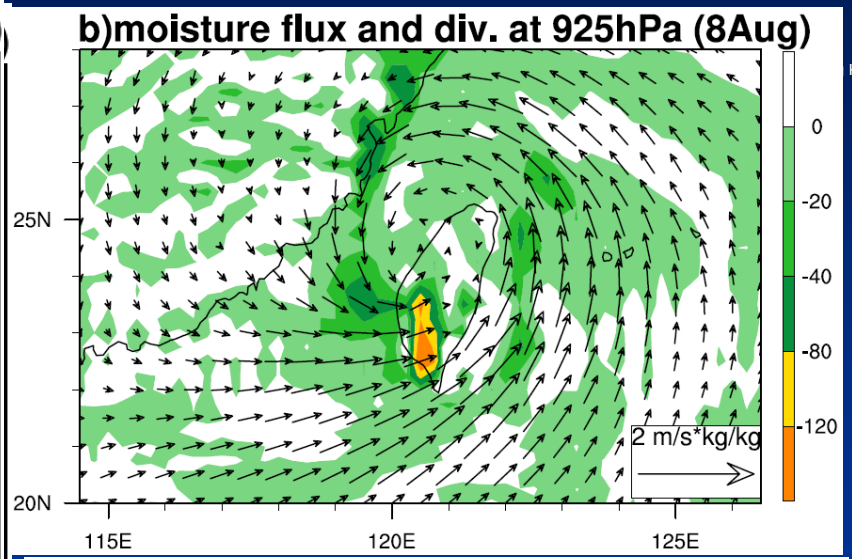
取自李明旭, 楊明仁等人(2005)

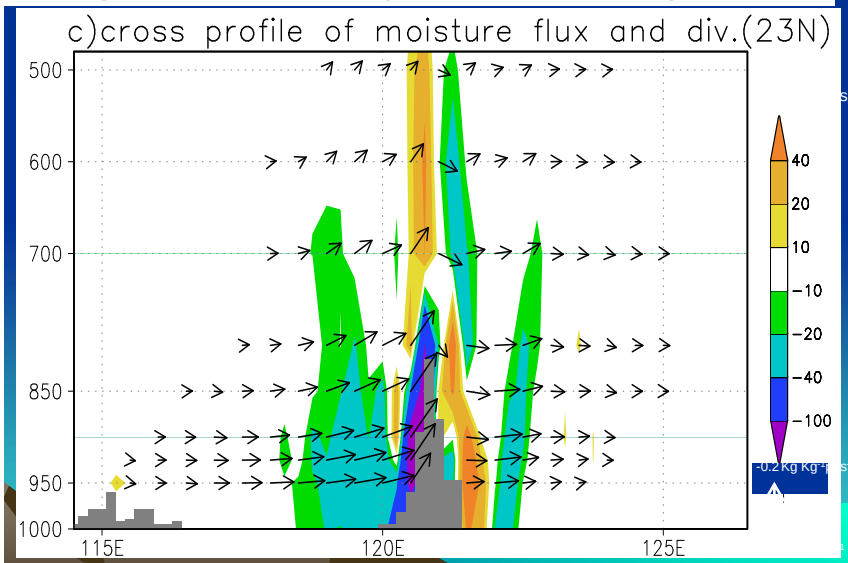
莫拉克颱風--破紀錄超大豪雨
長延時的持續性降雨



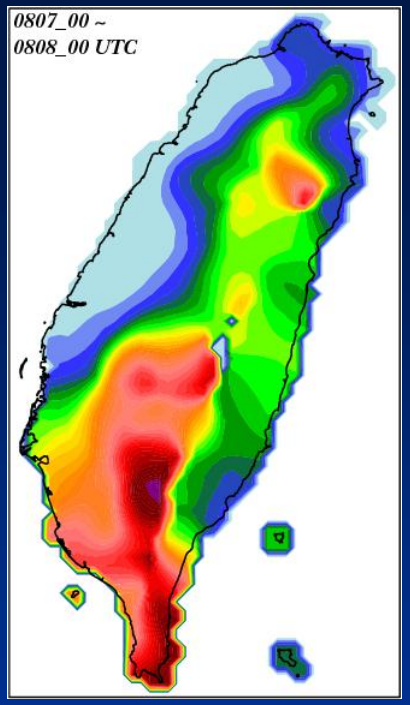
莫拉克颱風--地形抬升作用

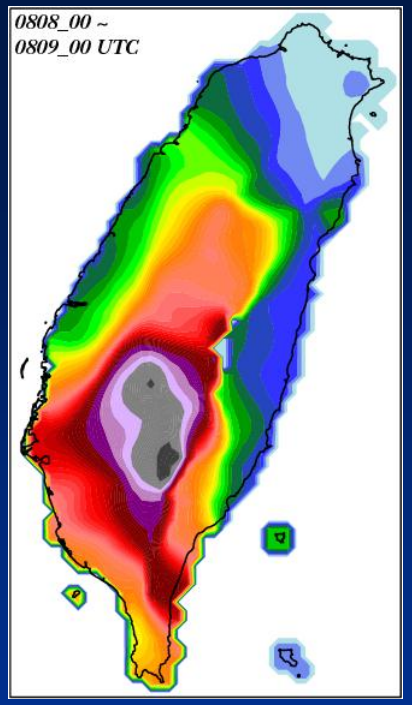


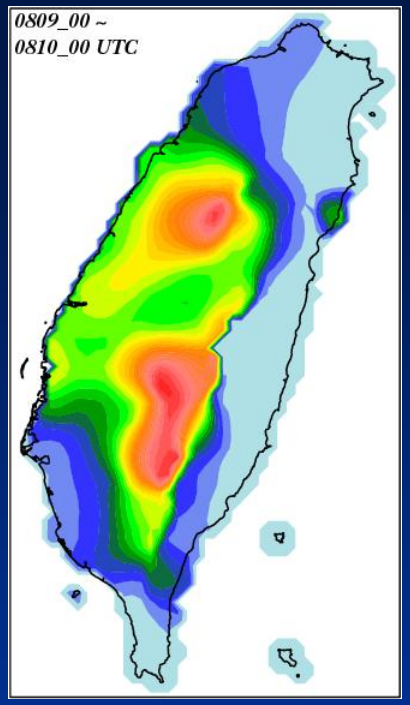




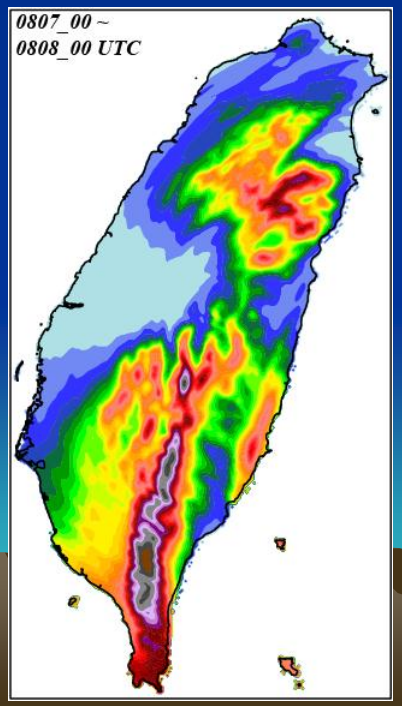
CWB
觀測分析

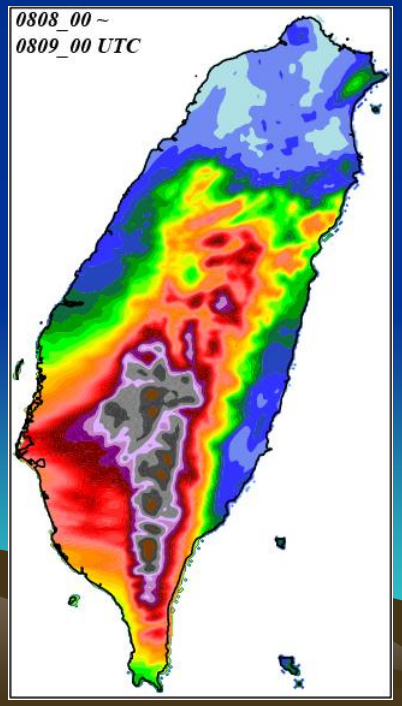


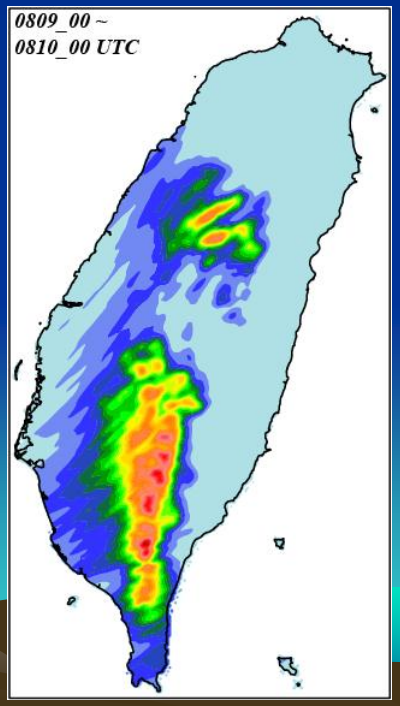


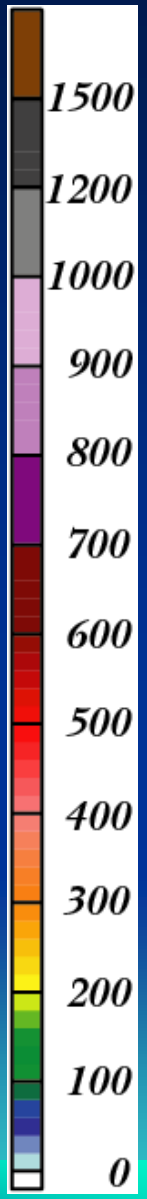


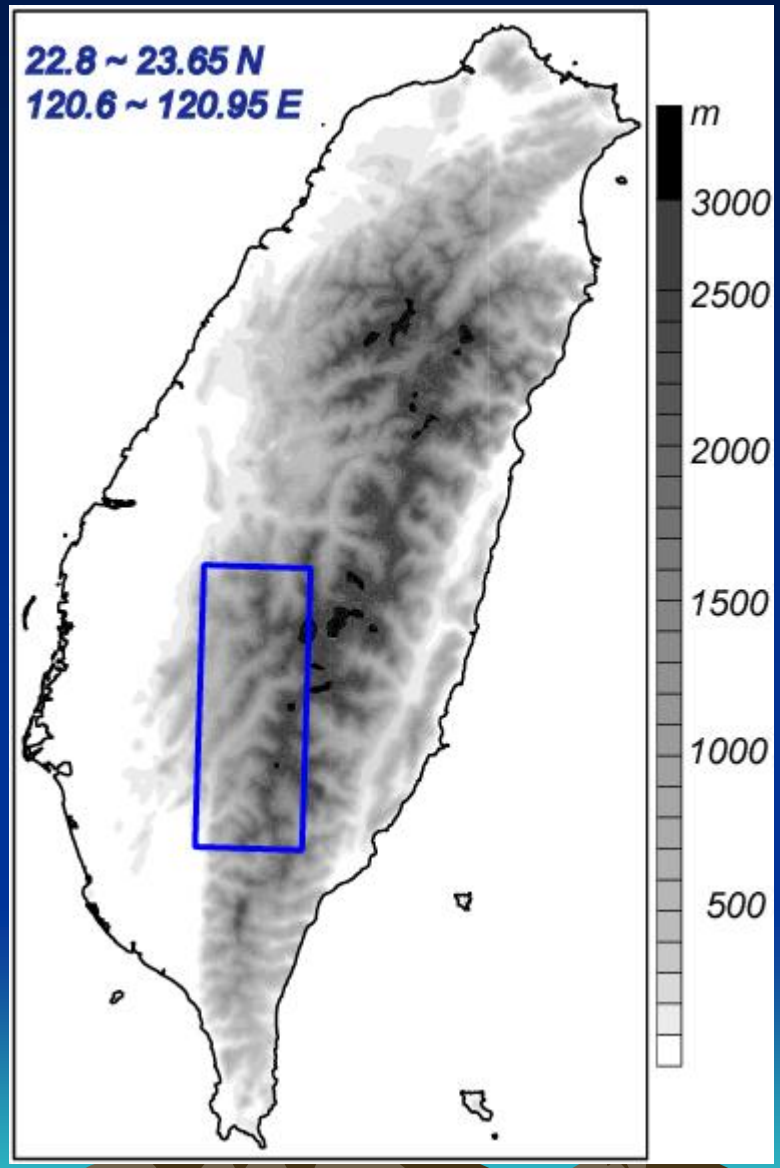
WRF (1 km)
電腦模擬



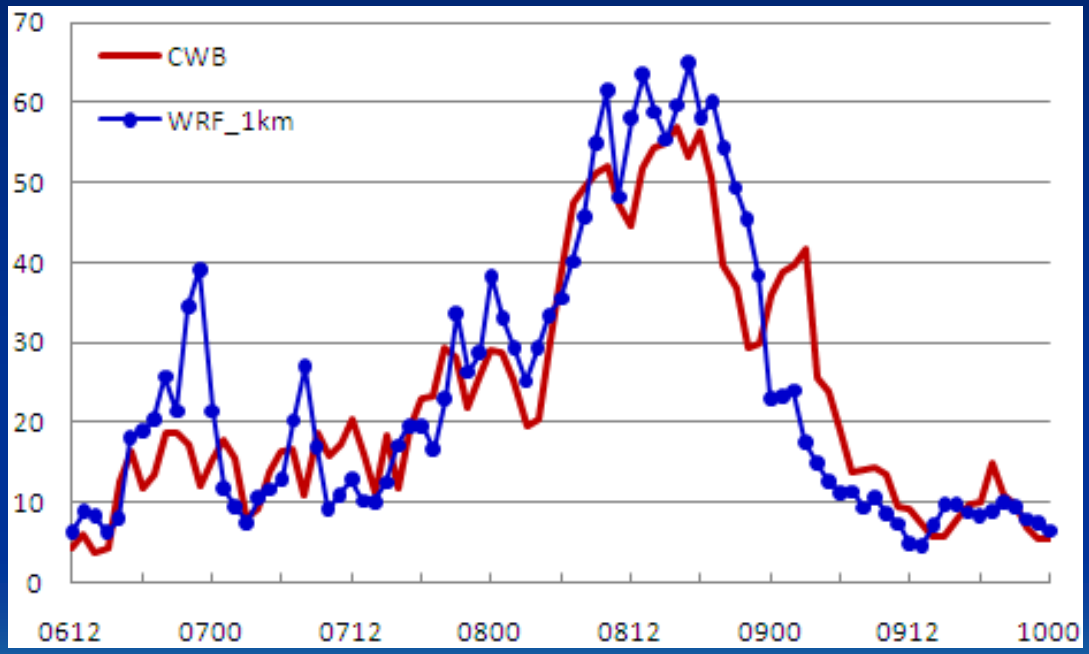




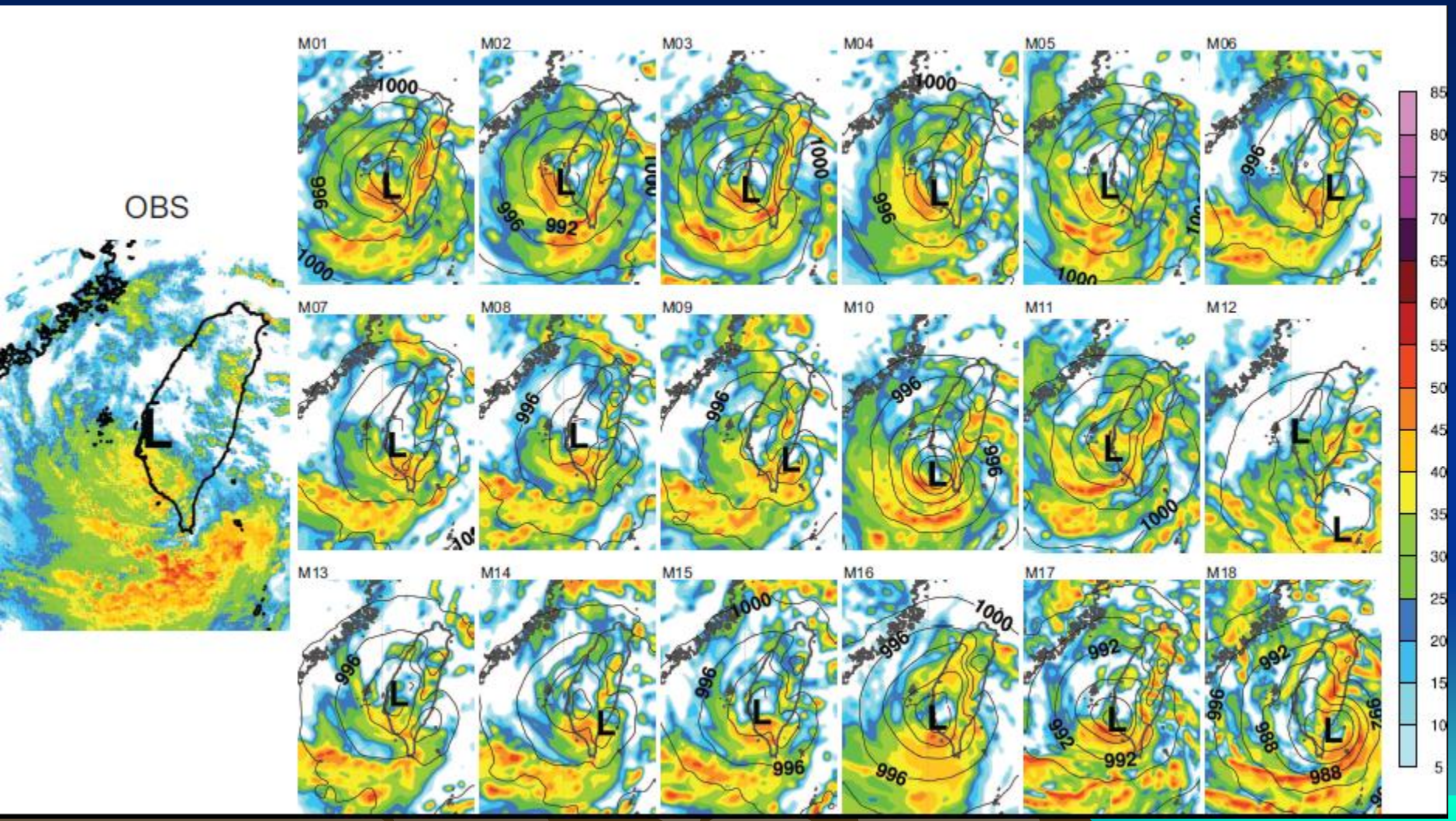




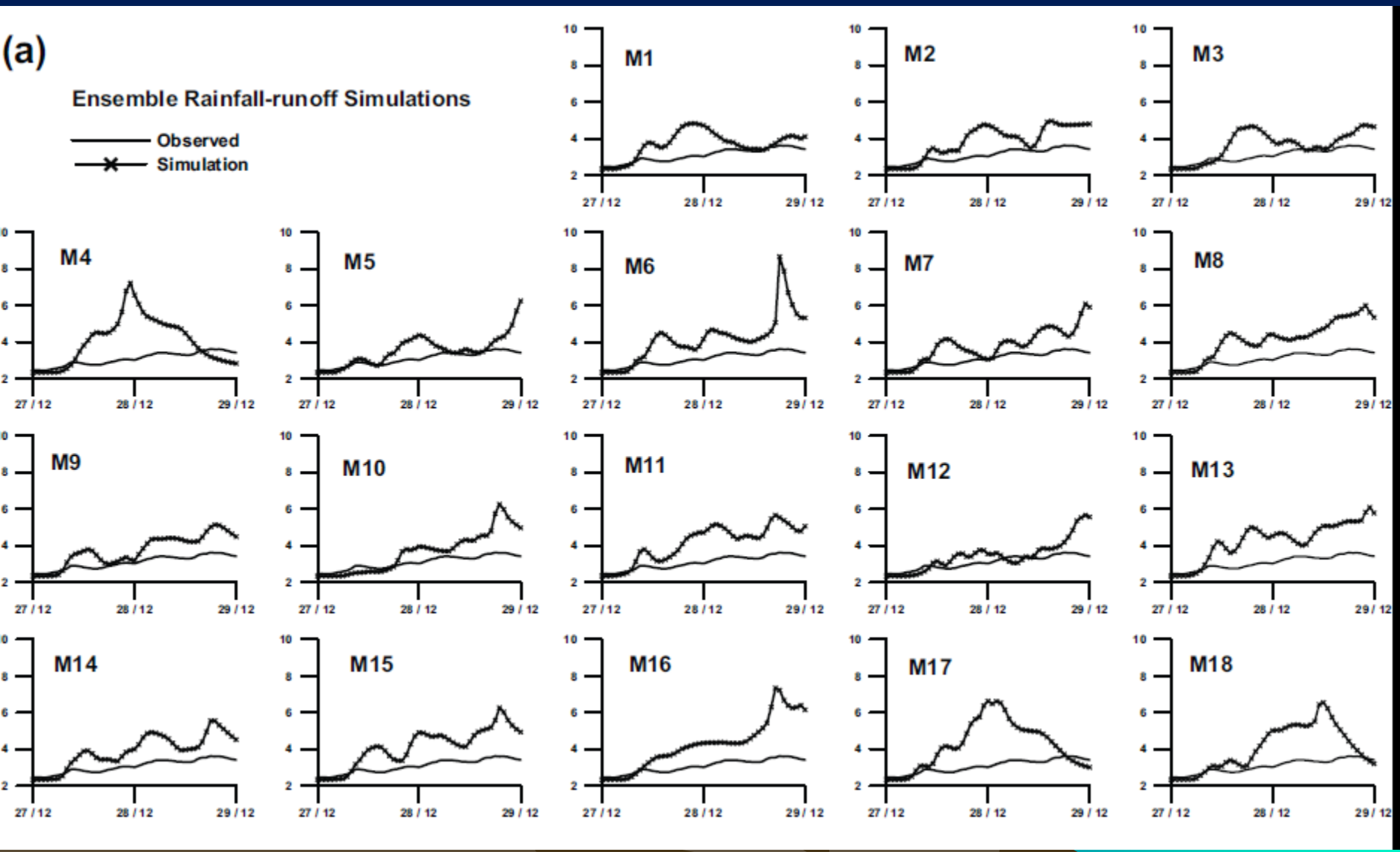
嘉南山區域平均降水時間序列分布 (mm)



系集模式雨量預報


OBS
M01
M02
M03
M04
M05
M06
M07
M08
M09
M10
M11
M12
M13
M14
M15
M16
M17
M18
L
1000
996
992
988
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5

系集模式集水區流量預報



結論

* 颱風為自然界最具破壞力的旋轉性流體, 造成台灣地區最大的氣象及水文災害.

* 颱風現象為大氣科學領域中多重尺度交互作用的複雜議題, 颱風路徑及伴隨風雨預報為科學上極為困難但於作業上極為重要的任務.

* 結合雷達即時觀測及數值模式發展, 提高定量降雨預報準確度.

* 結合氣象模式定量降雨預報及水文模式逕流預報, 提供流域之水位及流量預報.

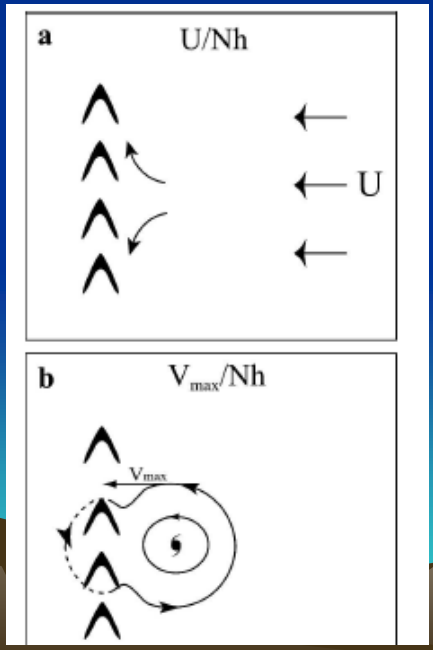
Thanks for your attention!

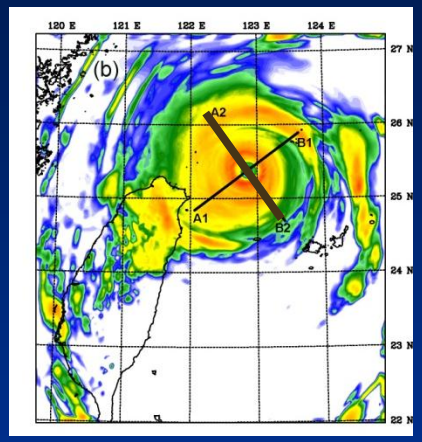
感謝大家!

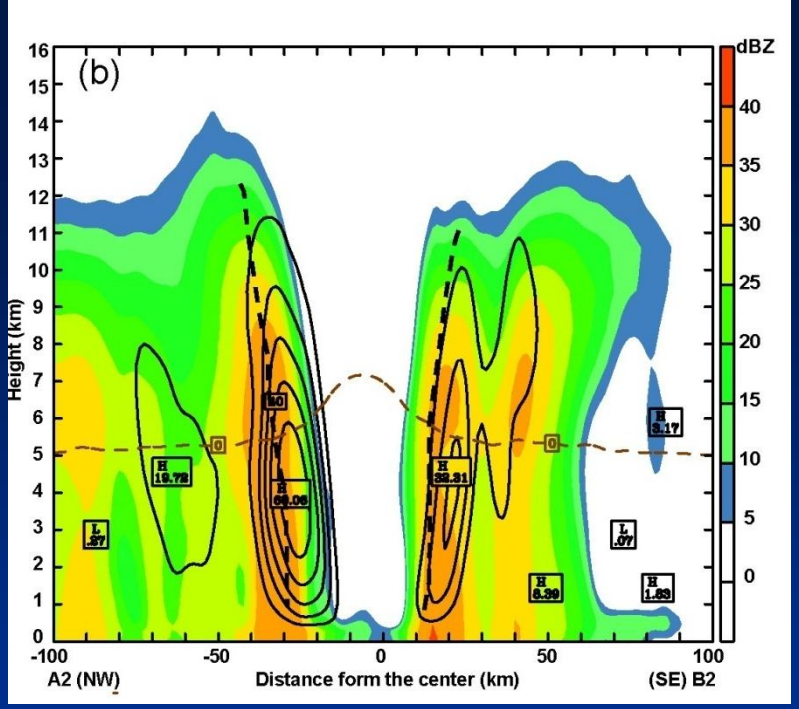
不連續颱風路徑
——理想化電腦數值模擬

Lin et al. (2005; JAS) :

- When the nondimensional parameter of *R/Ly* are small (large), the TC's track would be discontinuous (continuous), and the track deflection is large (small).
- Note that The parameter *Vmax/Nh* may be regarded as a vortex Froude number of the airstream associated with typhoon's tangential circulation. The parameter *Vmax/U* measures the relative strength of the typhoon vortex compared to the basic flow.

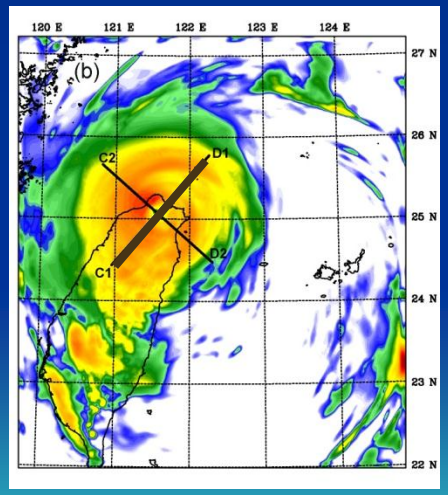


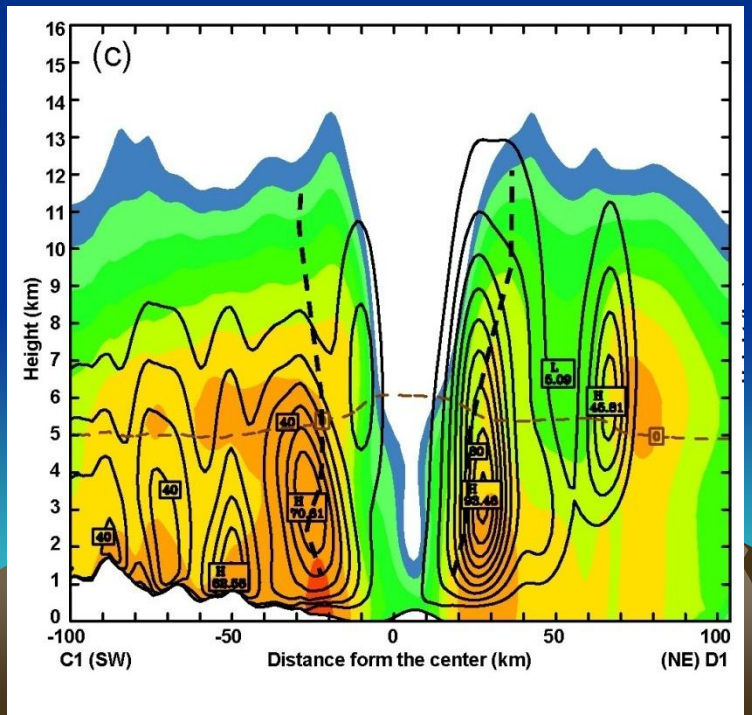




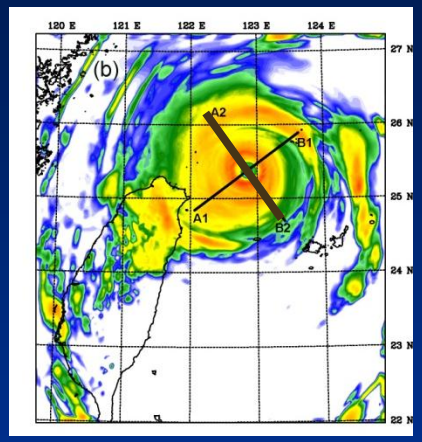
Before Landfall

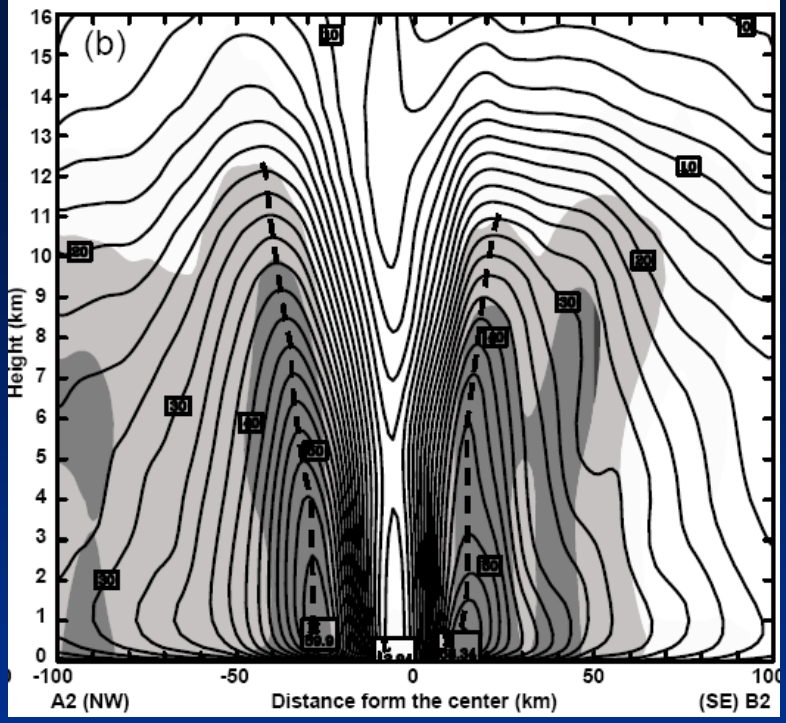
Radar Echo (color)
Condensational Heating (contour)





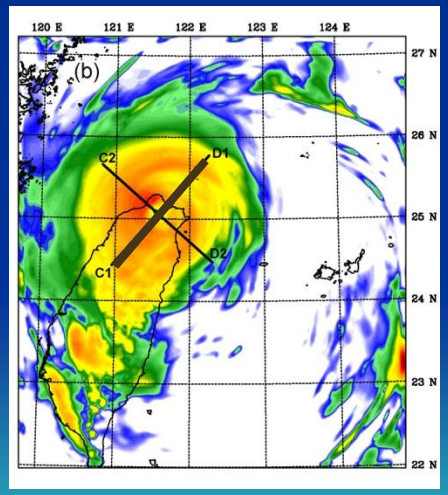
After Landfall

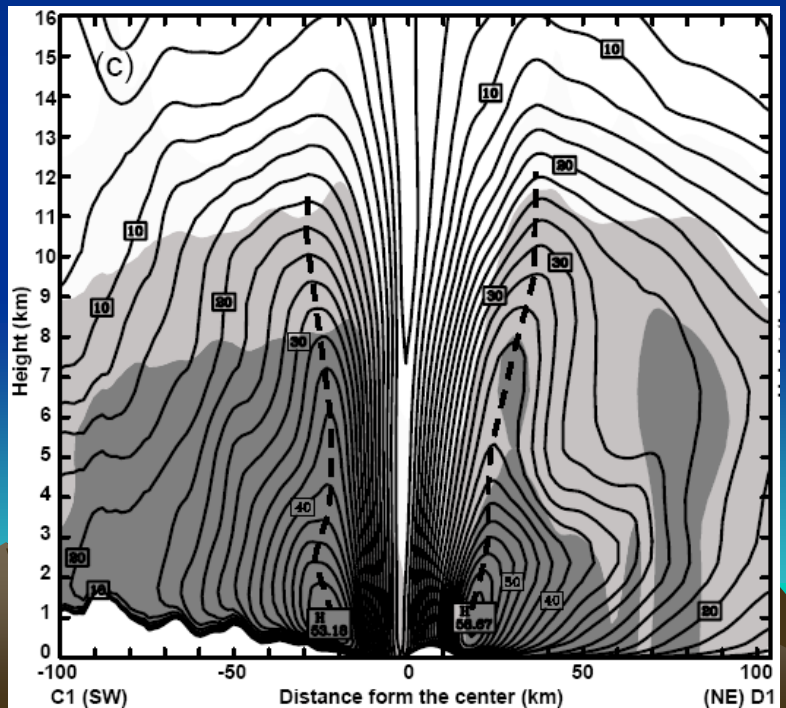




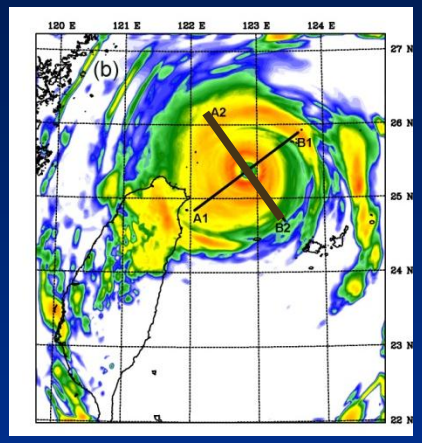
Before Landfall

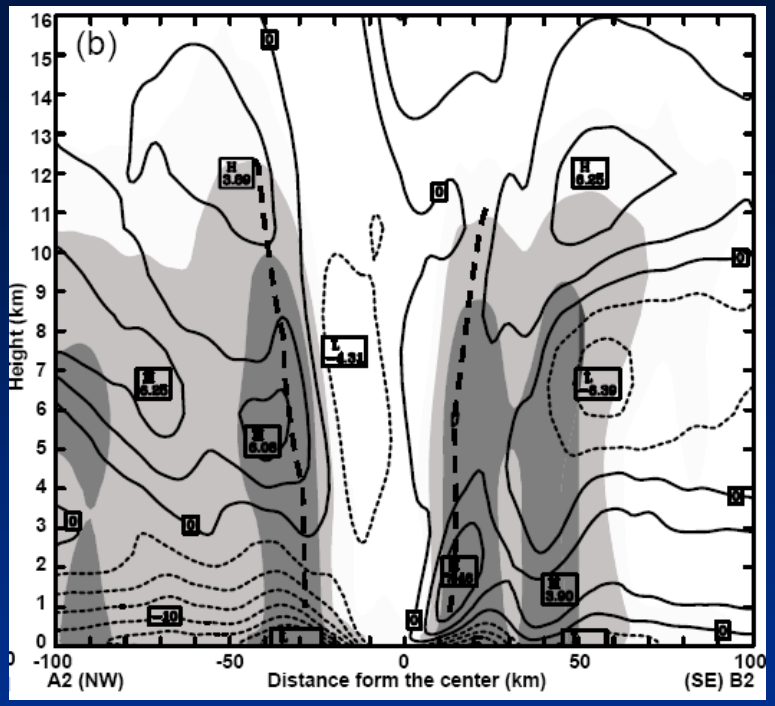
Radar Echo (shading)
Tangential Velocity (contour)





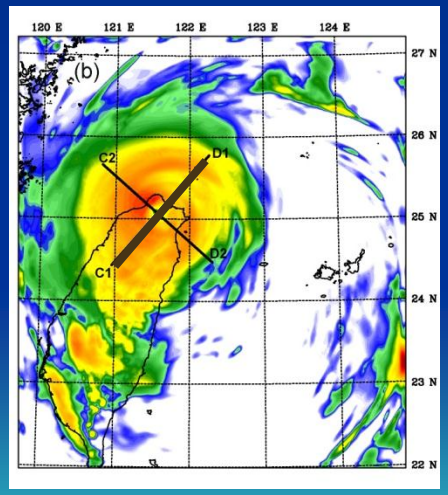
After Landfall

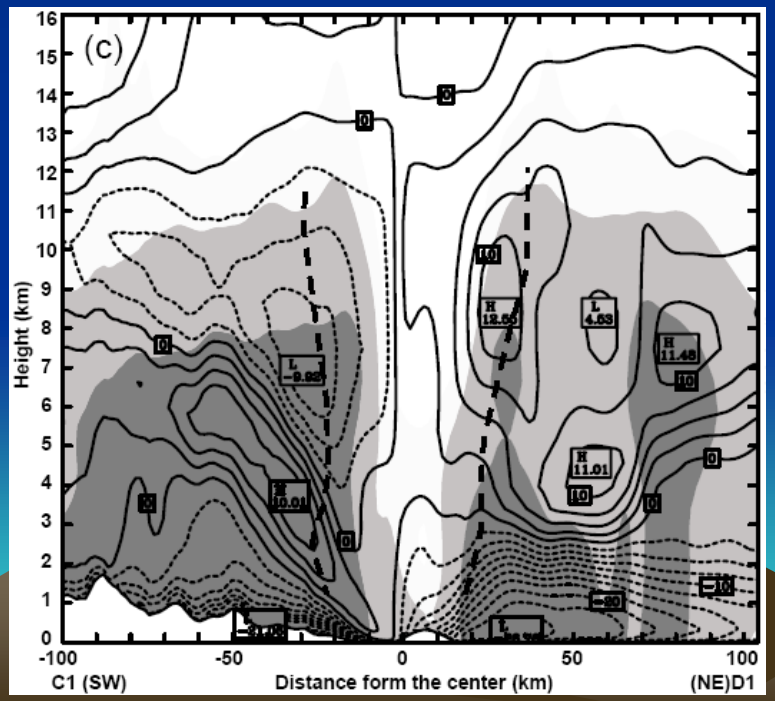




Before Landfall

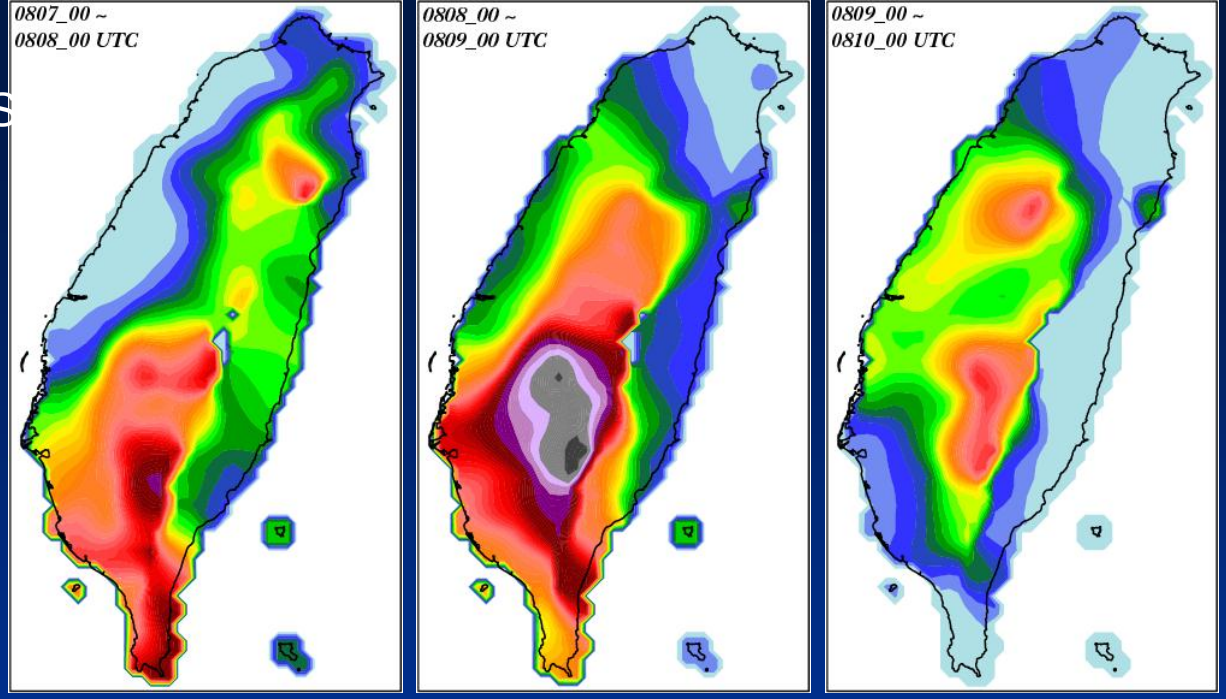
Radar Echo (shading)
Radial Velocity (contour)





After Landfall

CWB_OBS
觀測分析



WRF_
Run 1km
電腦模擬