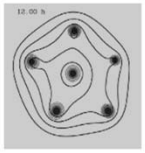
Extreme Rainfall in Taiwan and the interaction of typhoon with monsoons





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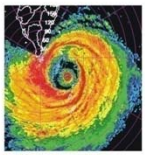
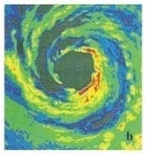
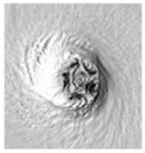
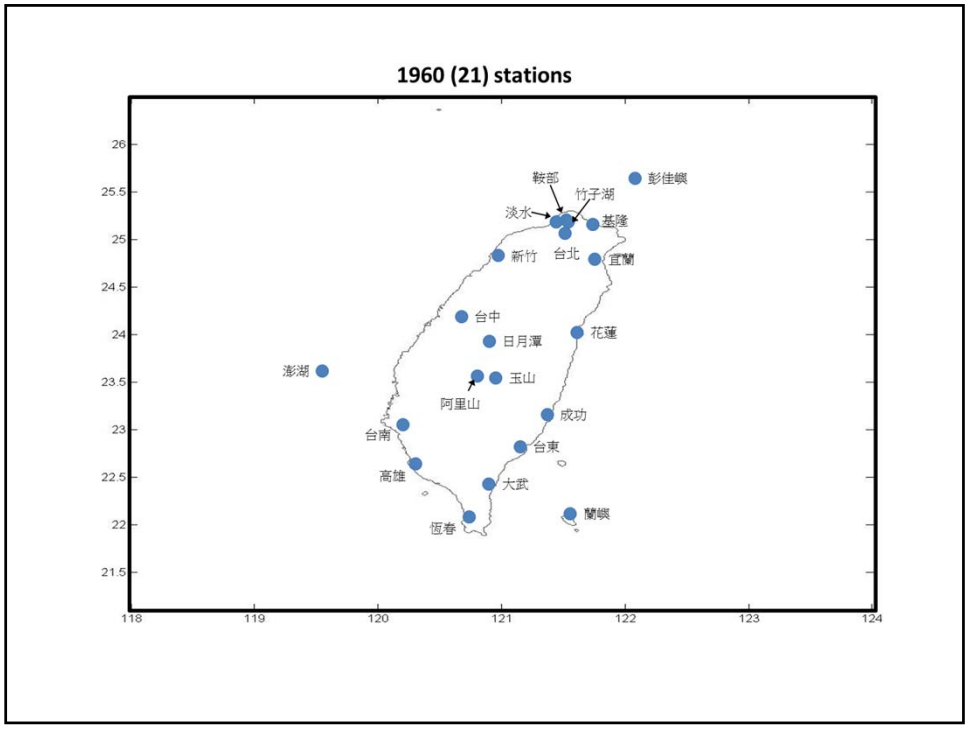
International Workshop on Typhoon and Flood (Taiwan)
June 23, 2011

Robert Fovell, C.C. Wang, and F.C. Chien
Shih-Hao SU, Li-Huan HSU, Yi-Ting YANG and Hungjui YU

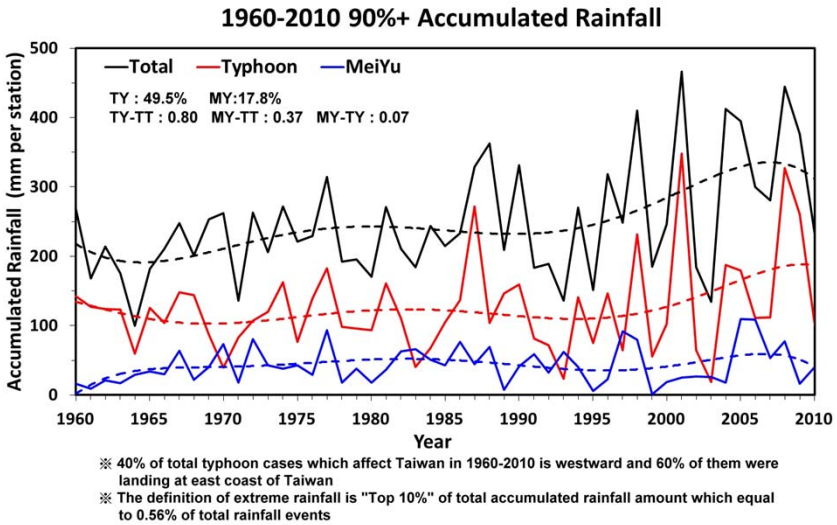




OUTLINES

- Introduction – 50 years of rainfall data
- Typhoon interaction with monsoon ; mesoscale convections
- Slow movement Typhoon
- Rainfall and typhoon translation speed
- Summary

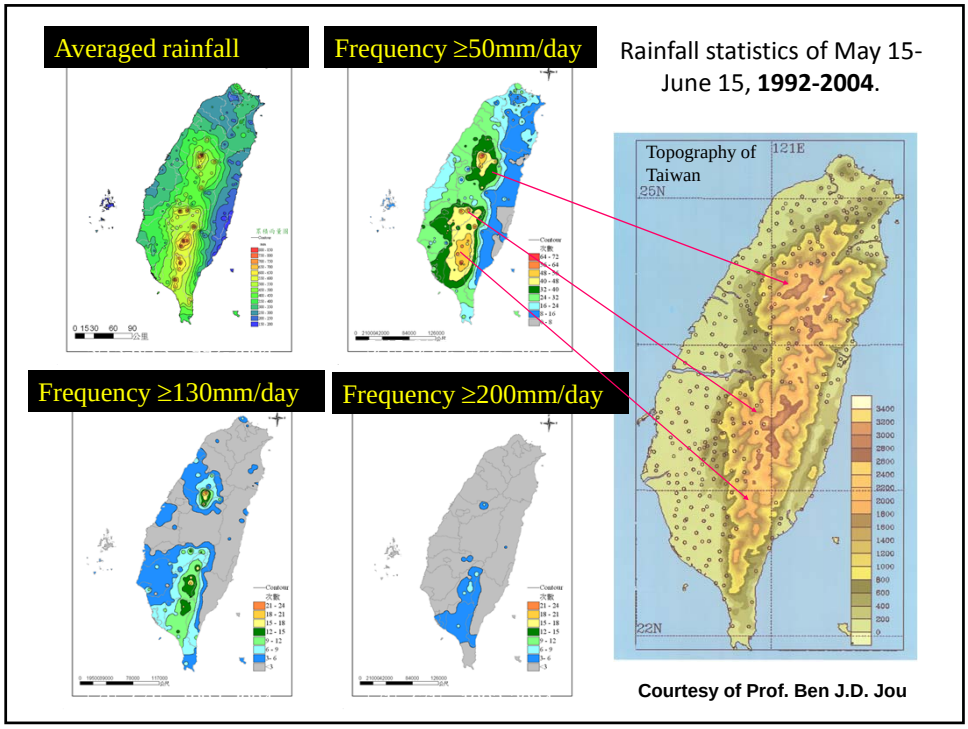


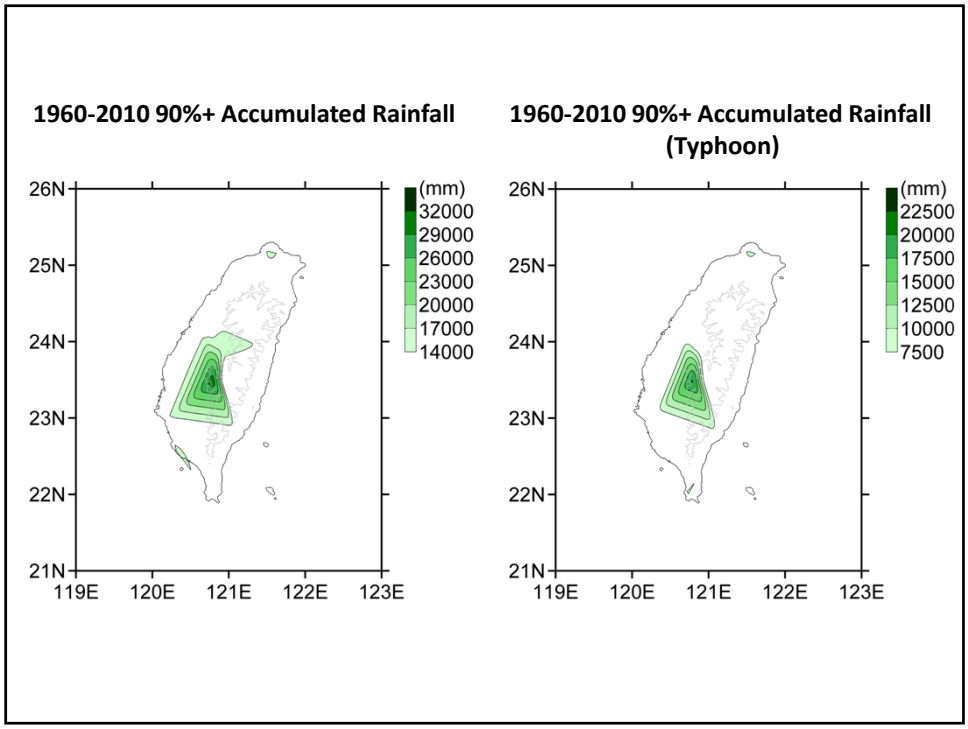
Taiwan extreme rainfall



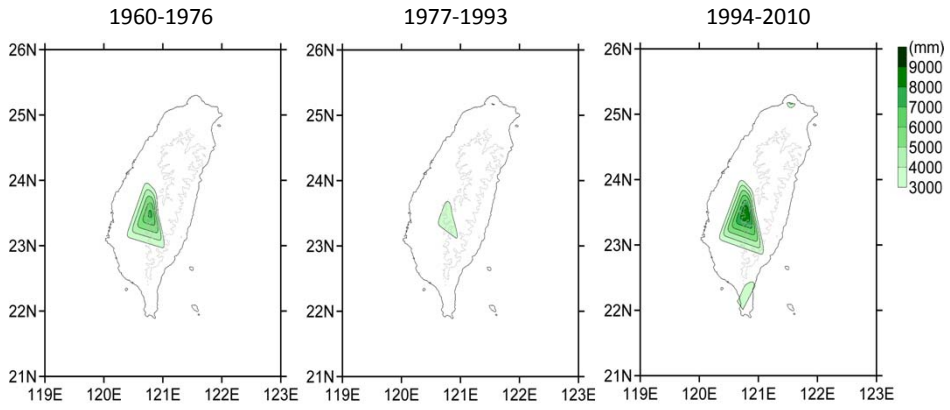
※ 40% of total typhoon cases which affect Taiwan in 1960-2010 is westward and 60% of them were landing at east coast of Taiwan

※ The definition of extreme rainfall is "Top 10%" of total accumulated rainfall amount which equal to 0.56% of total rainfall events


Averaged rainfall
Frequency ≥50mm/day
Rainfall statistics of May 15-June 15, **1992-2004**.
Topography of Taiwan
121E
25N
22N
Frequency ≥130mm/day
Frequency ≥200mm/day
Courtesy of Prof. Ben J.D. Jou


1960-2010 90%+ Accumulated Rainfall
1960-2010 90%+ Accumulated Rainfall (Typhoon)
(mm)
32000
29000
26000
23000
20000
17000
14000
(mm)
22500
20000
17500
15000
12500
10000
7500
26N
25N
24N
23N
22N
21N
119E
120E
121E
122E
123E

90% Accumulated Rainfall (Typhoon)



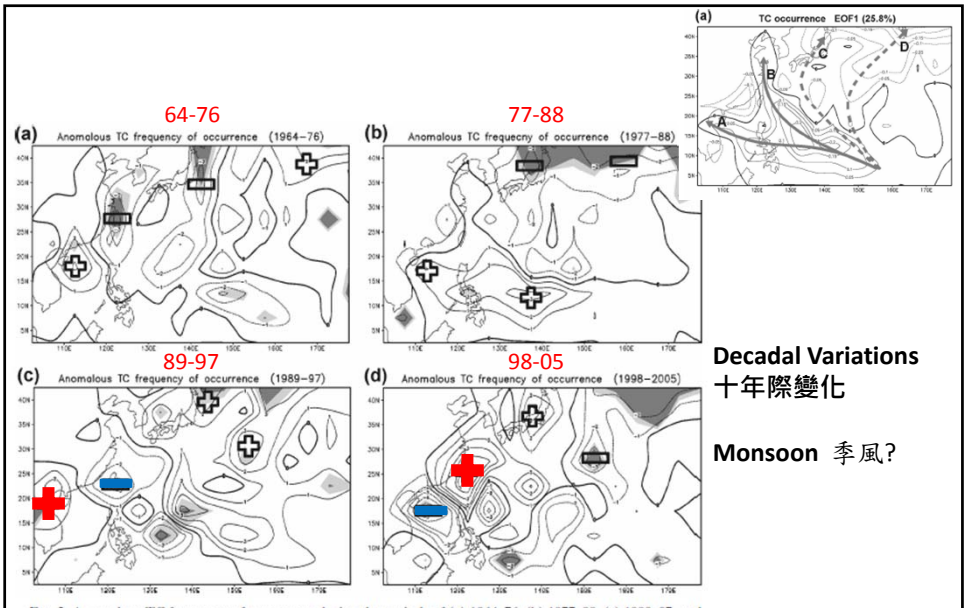


FIG. 2. Anomalous TC frequency of occurrence during the periods of (a) 1964–76, (b) 1977–88, (c) 1989–97, and (d) 1998–2005. Dark and light shadings indicate the areas with anomalies significant at the 95% and 90% confidence levels, respectively. Plus-shaped boxes (rectangular-shaped) indicate the areas with higher (lower) TS frequency of occurrence.

Decadal Variations
十年際變化

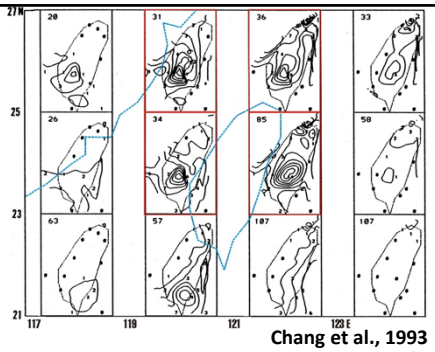
Monsoon 季風?

Liu and Chan 2008

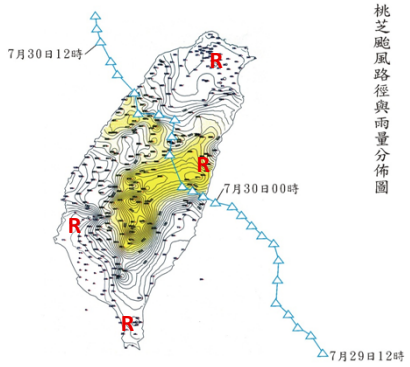
CWB is capable of 24 hr and 100km scale ppn (phase locked with topography)

0 to 12 hr and 10 km ppn remain biggest challenges

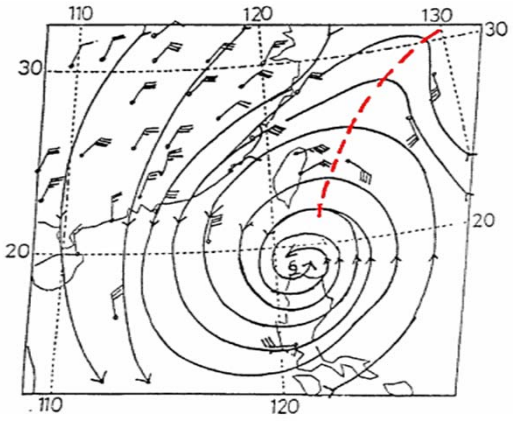
355mm in 5 hr in the city of KaoShung (5 pm to 10 pm at the beginning of the rush hour)
Mesoscale convections



Chang et al., 1993



東北季風與秋季颱風共伴環流
Interaction of NE monsoon with Typhoon



Courtesy of Dr. S.S. Chi

Northeast Monsoon surge

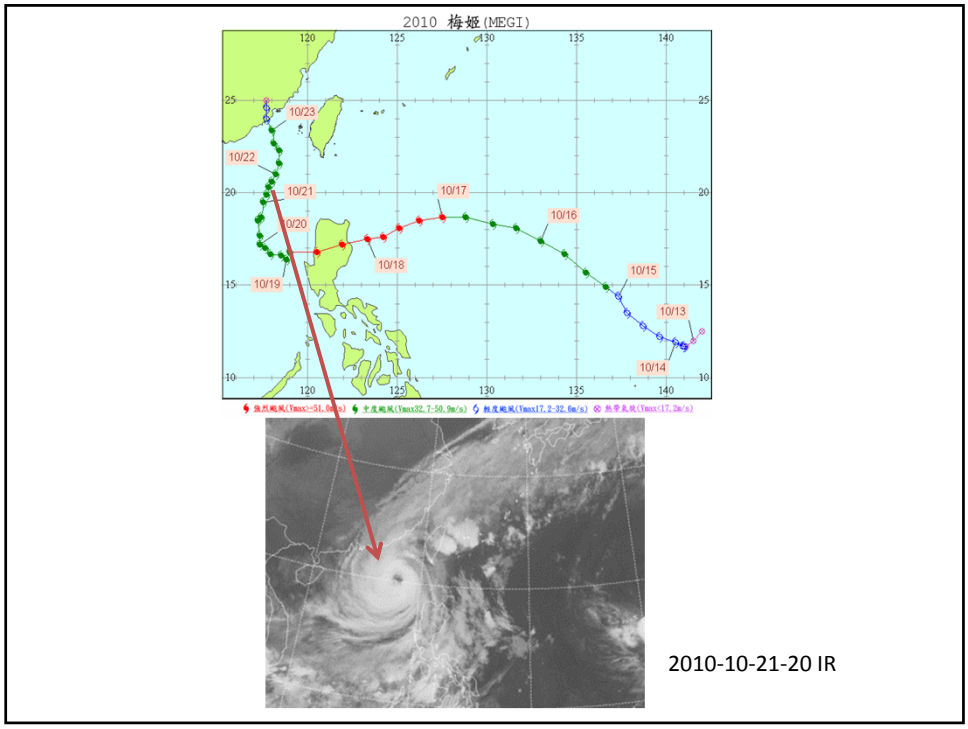
Typhoon Lynn (1987)

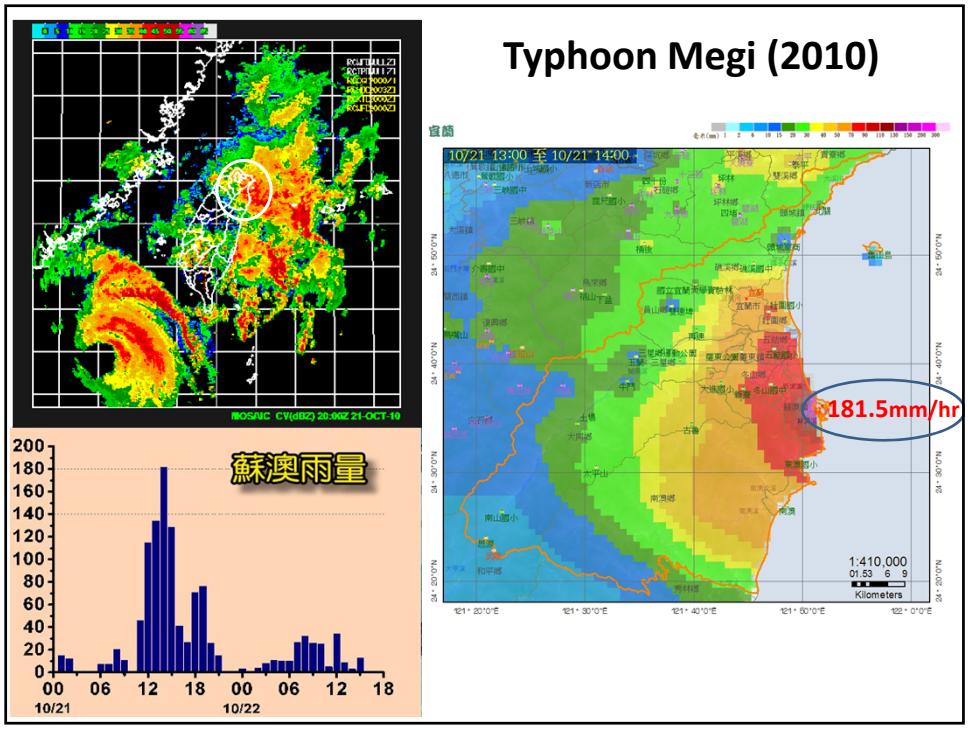
Flood in Taipei city

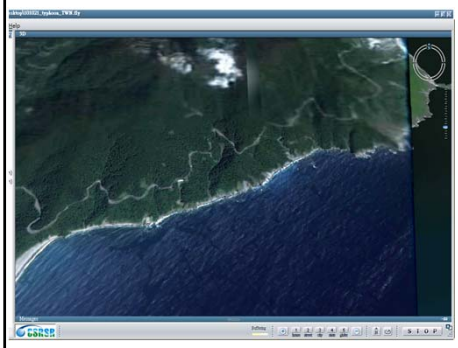
Typhoon Megi (2010)

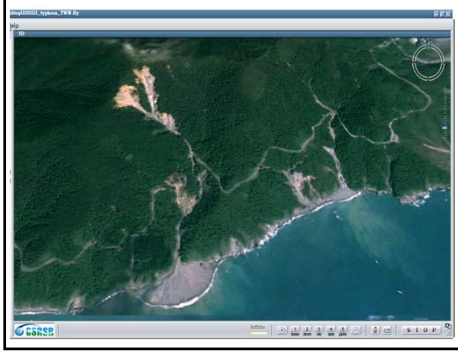
颱風位於巴士海峽，北部東北部持續降雨

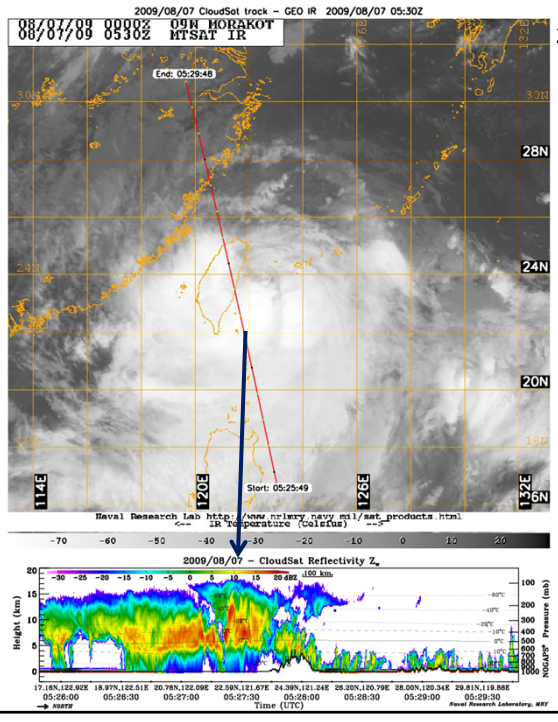
中尺度對流系統與地形作用


2010 梅姬(MEGI)
10/23
10/22
10/21
10/20
10/19
10/18
10/17
10/16
10/15
10/13
10/14
2010-10-21-20 IR


Typhoon Megi (2010)
蘇澳雨量
200
180
160
140
120
100
80
60
40
20
0
00 06 12 18 00 06 12 18
10/21
10/22
宜蘭
10/21 13:00 至 10/21 14:00
181.5mm/hr
1:410,000
Kilometers





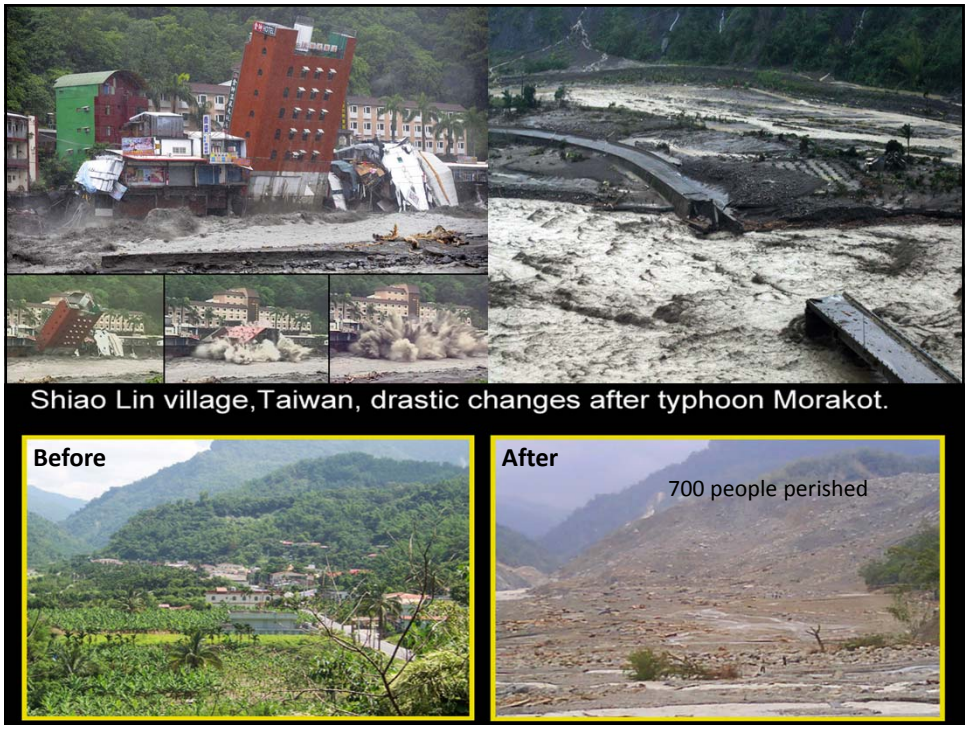


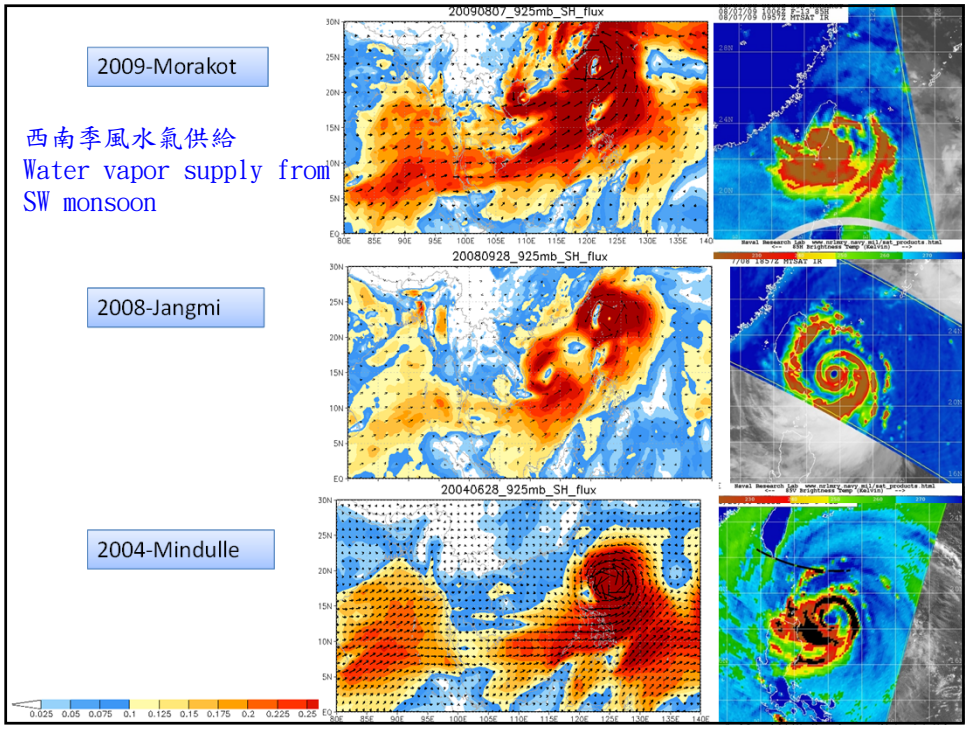
2009/8/7 CloudSat

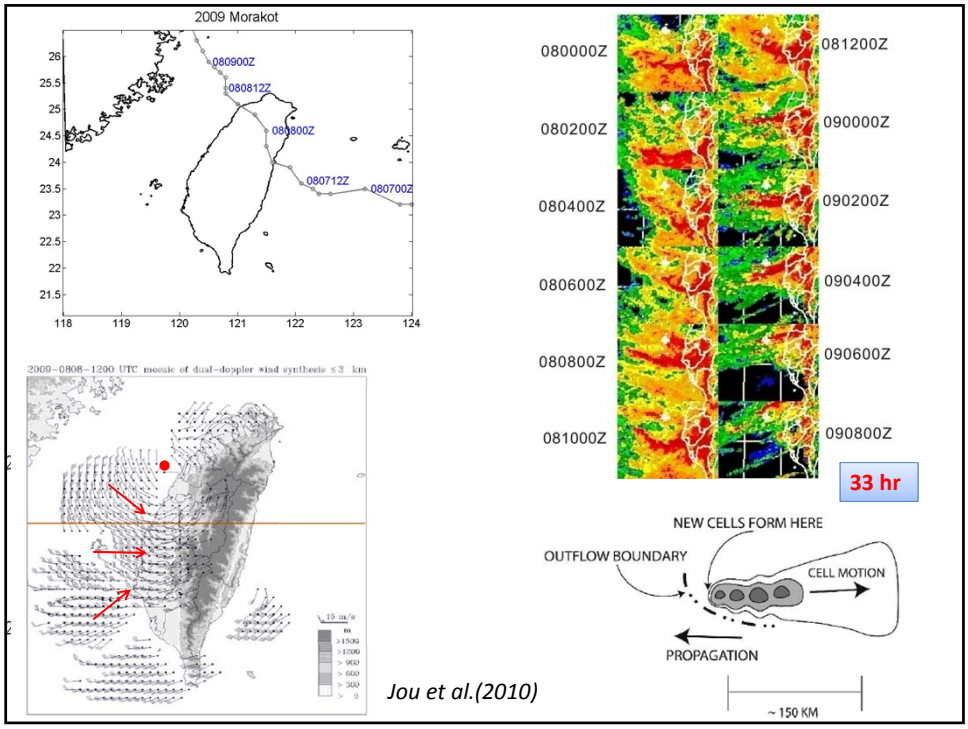
Typhoon Morakot (2009)

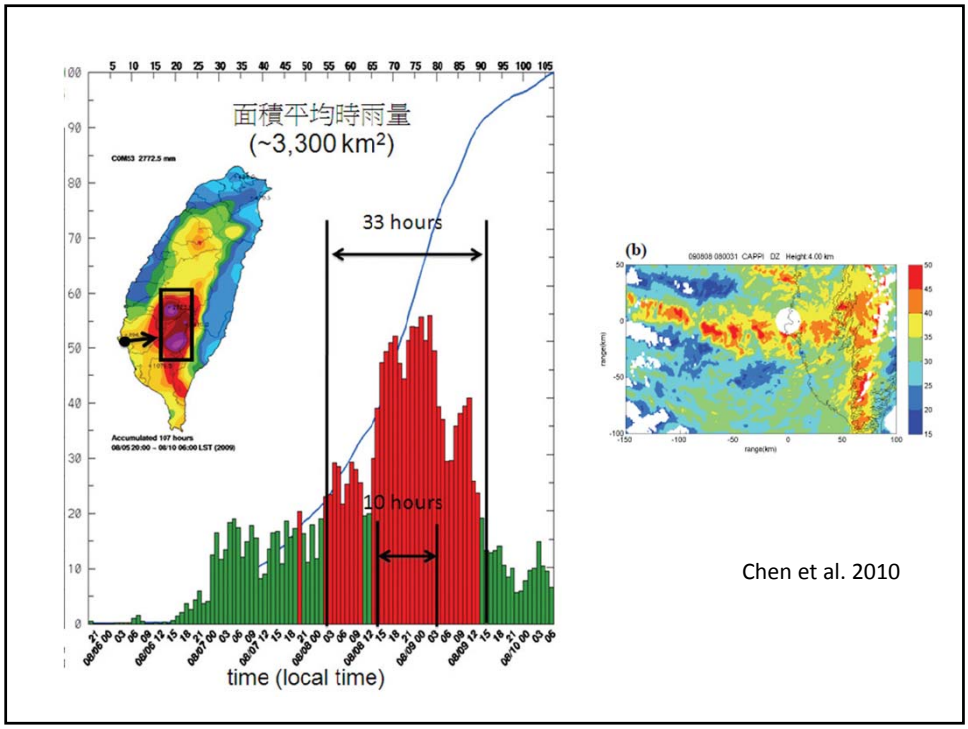
Deep convections in sourth

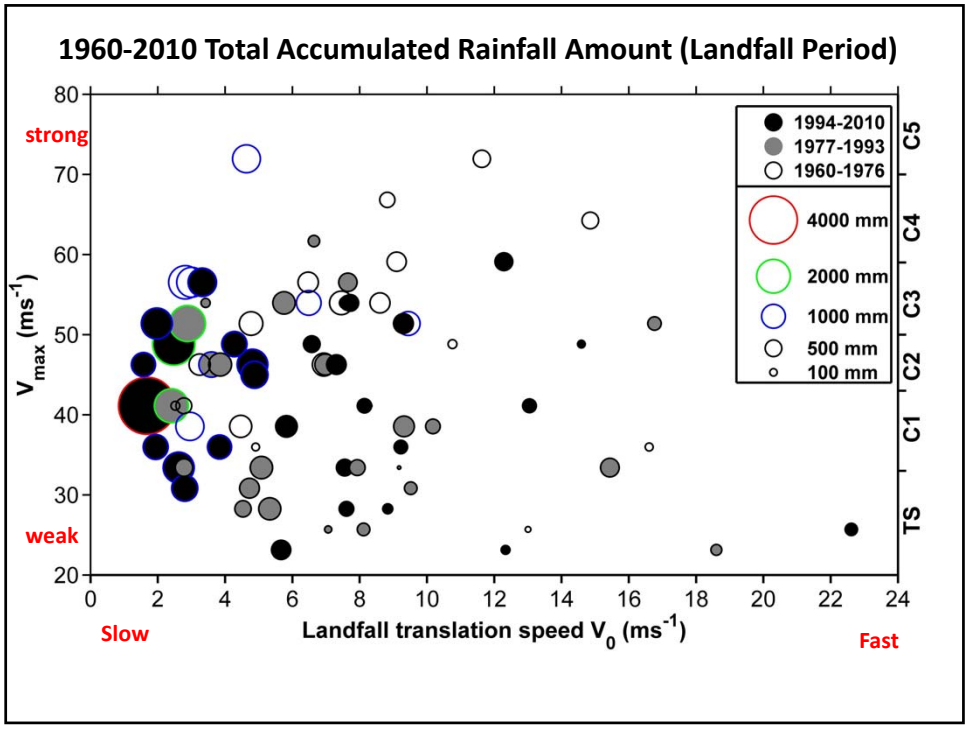
Chien and Kuo, 2010

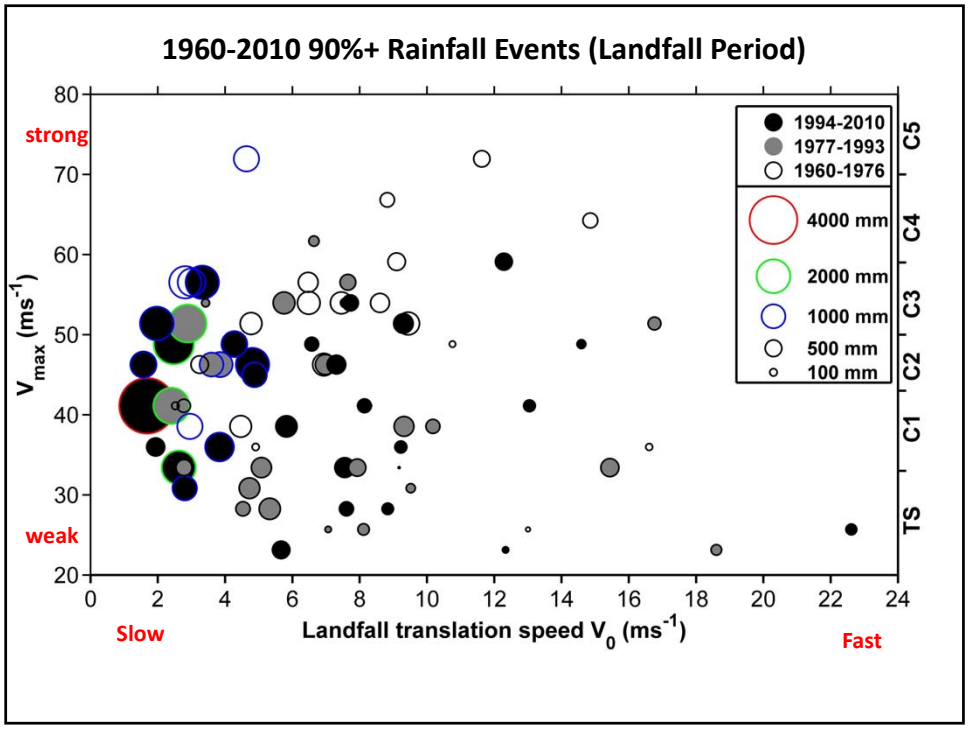

Shiao Lin village,Taiwan, drastic changes after typhoon Morakot.
Before
After
700 people perished

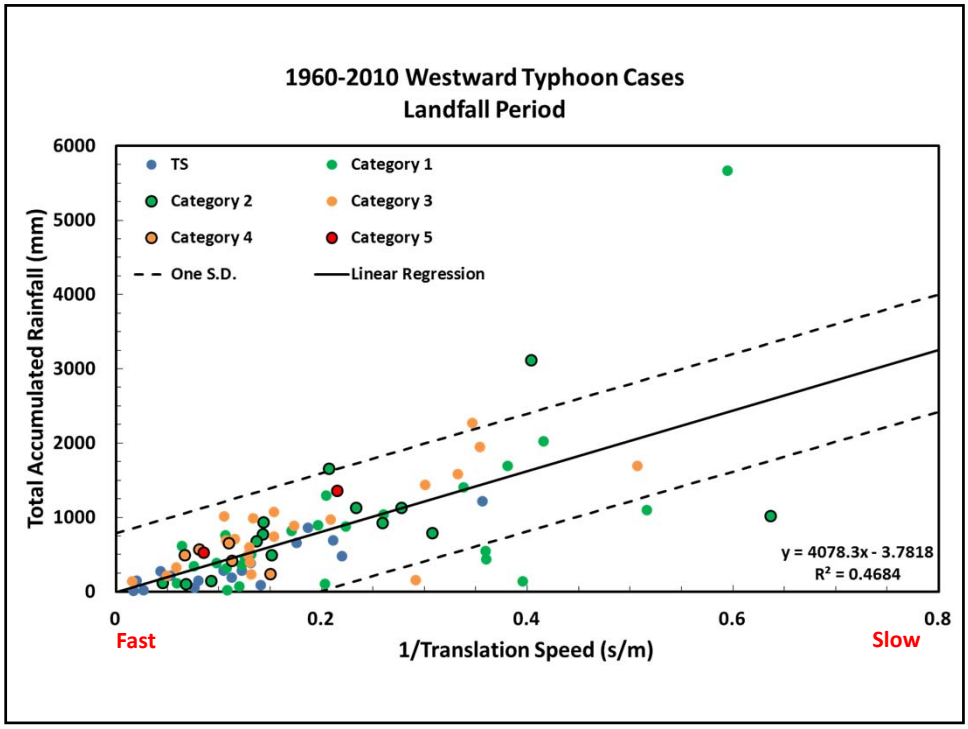

2009-Morakot
西南季風水氣供給
Water vapor supply from SW monsoon
2008-Jangmi
2004-Mindulle
20090807_925mb_SH_flux
20080928_925mb_SH_flux
20040628_925mb_SH_flux

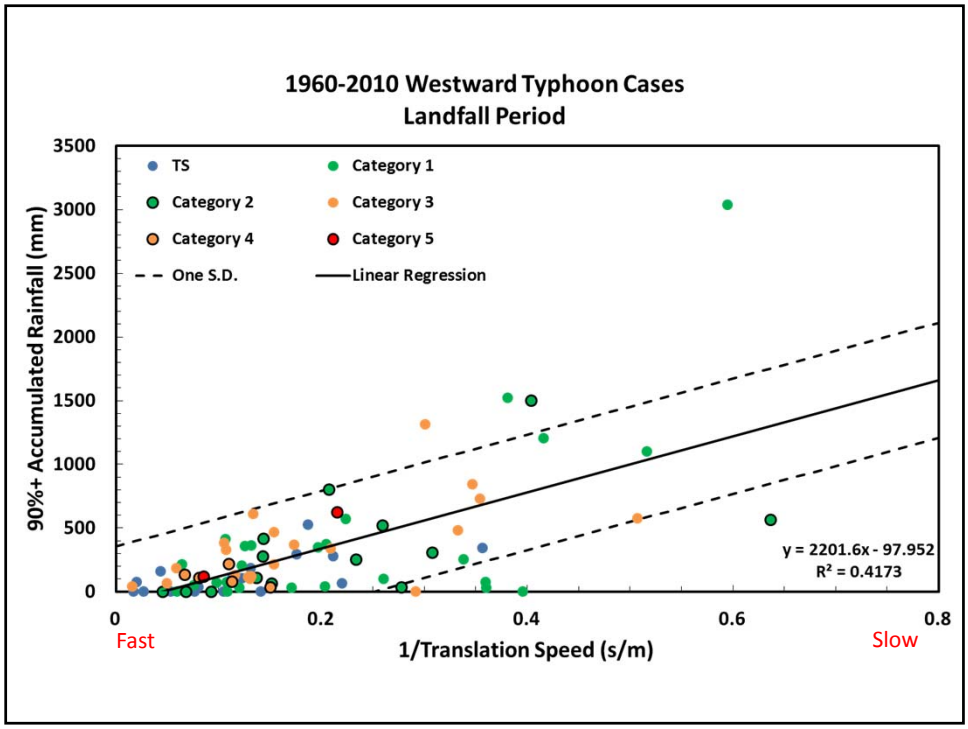

2009 Morakot
080900Z
080812Z
080800Z
080712Z
080700Z
080000Z
080200Z
080400Z
080600Z
080800Z
081000Z
081200Z
090000Z
090200Z
090400Z
090600Z
090800Z
33 hr
NEW CELLS FORM HERE
OUTFLOW BOUNDARY
CELL MOTION
PROPAGATION
~ 150 KM
Jou et al.(2010)


面積平均時雨量
(~3,300 km²)
33 hours
10 hours
time (local time)
(b)
Chen et al. 2010

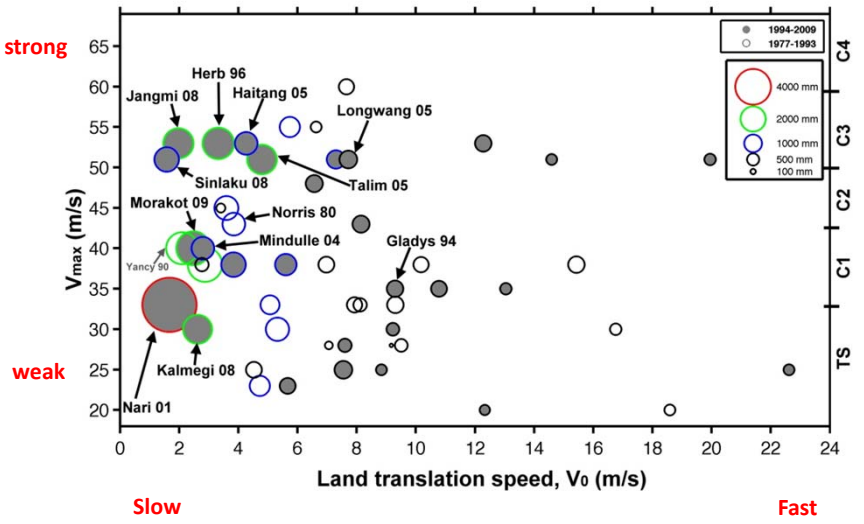

1960-2010 Total Accumulated Rainfall Amount (Landfall Period)
strong
weak
Slow
Fast
V_{max} (ms^{-1})
Landfall translation speed V_0 (ms^{-1})
1994-2010
1977-1993
1960-1976
4000 mm
2000 mm
1000 mm
500 mm
100 mm
C5
C4
C3
C2
C1
TS


1960-2010 90%+ Rainfall Events (Landfall Period)
strong
weak
Slow
Fast
V_{max} (ms^{-1})
Landfall translation speed V_0 (ms^{-1})
1994-2010
1977-1993
1960-1976
4000 mm
2000 mm
1000 mm
500 mm
100 mm
C5
C4
C3
C2
C1
TS


1960-2010 Westward Typhoon Cases
Landfall Period
TS
Category 1
Category 2
Category 3
Category 4
Category 5
One S.D.
Linear Regression
Total Accumulated Rainfall (mm)
6000
5000
4000
3000
2000
1000
0
y = 4078.3x - 3.7818
R² = 0.4684
0
0.2
0.4
0.6
0.8
Fast
Slow
1/Translation Speed (s/m)

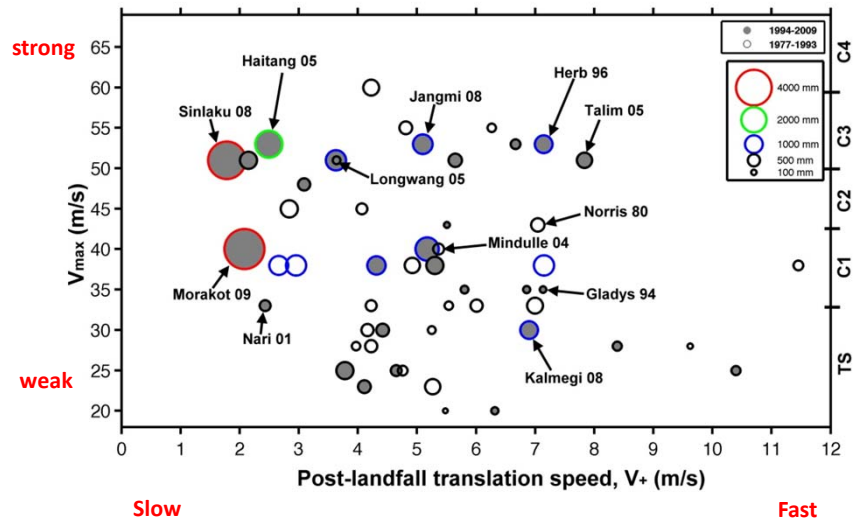

1960-2010 Westward Typhoon Cases
Landfall Period
TS
Category 1
Category 2
Category 3
Category 4
Category 5
One S.D.
Linear Regression
90%+ Accumulated Rainfall (mm)
3500
3000
2500
2000
1500
1000
500
0
y = 2201.6x - 97.952
R² = 0.4173
0
0.2
0.4
0.6
0.8
Fast
Slow
1/Translation Speed (s/m)

1977-2010 Westward Typhoon cases (Landfall Period)



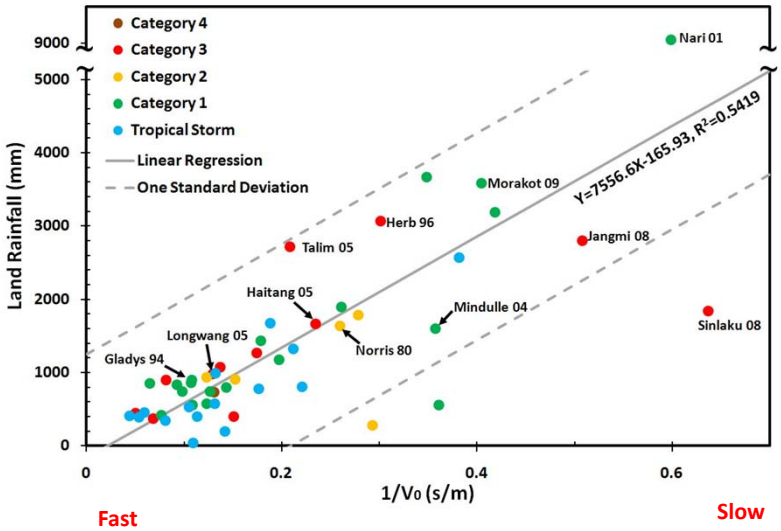
Chien and Kuo, 2010

1977-2010 Westward Typhoon cases (Post-landfall Period)



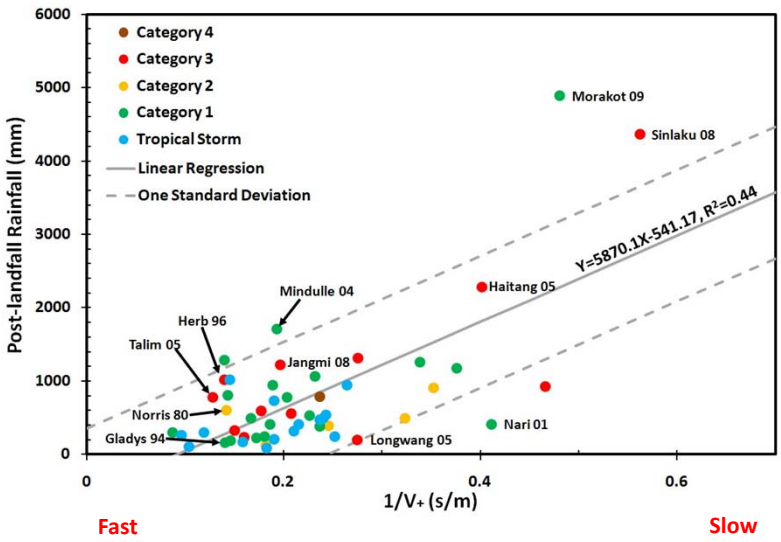
Chien and Kuo, 2010

1977-2010 Westward Typhoon cases (Landfall Period)

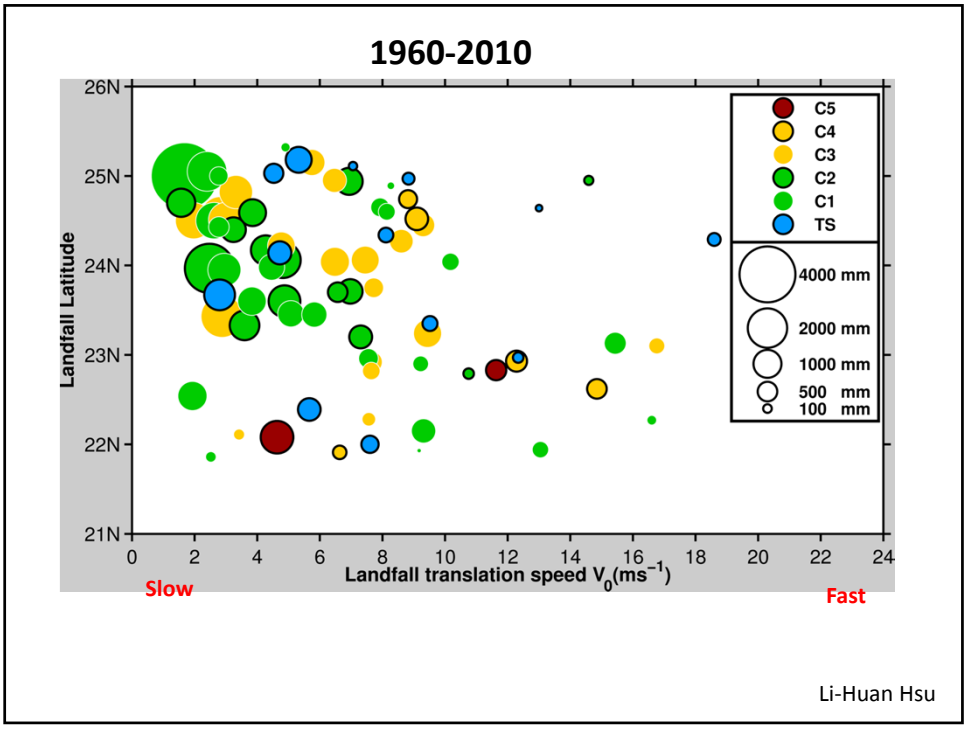


Chien and Kuo, 2010

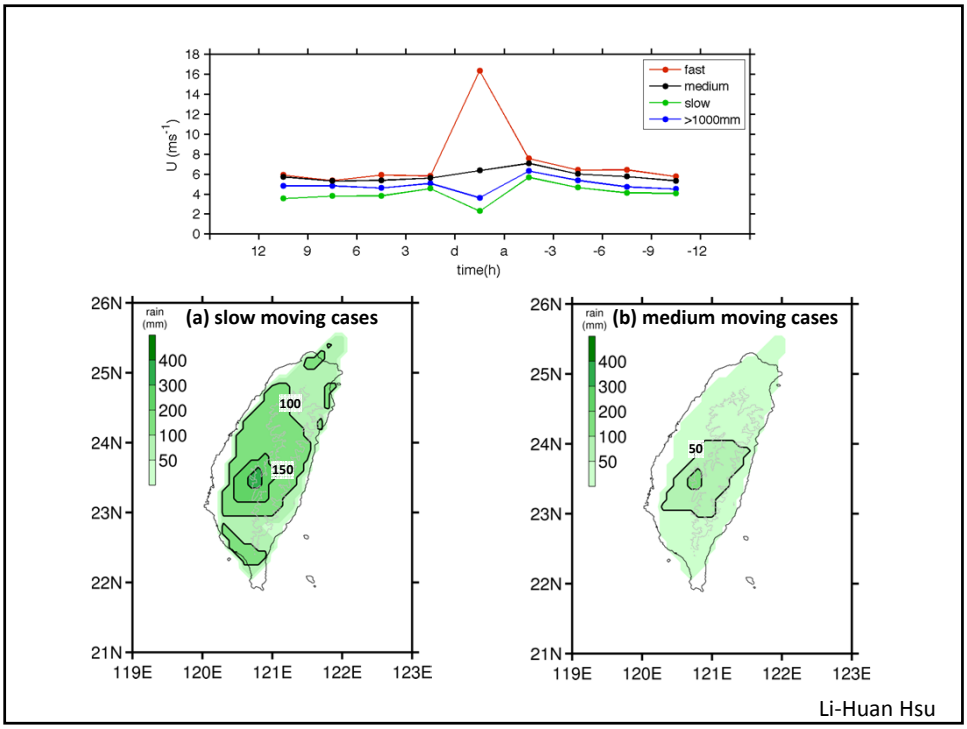
1977-2010 Westward Typhoon cases (Post-landfall Period)



Chien and Kuo, 2010



Li-Huan Hsu



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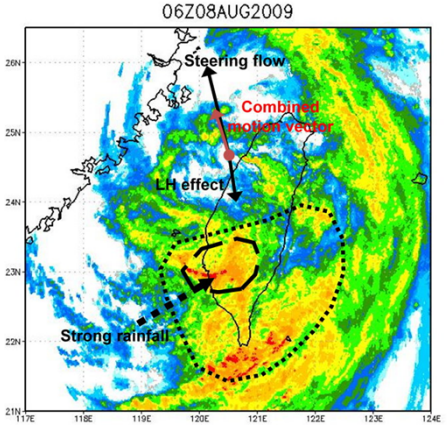
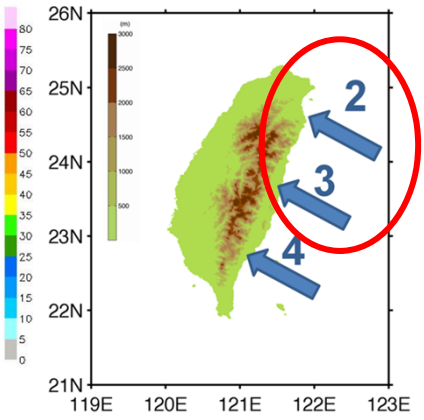
- **Hypothesis**
  - **Diabatic heating release of rainfall pattern phased locked by Taiwan topography will modify the distribution of potential vorticity and tend to slow down the translation speed of Typhoon.**



CWB radar reflectivity composite (dBZ)
(Courtesy of Prof. C.C. Wang)



Diagnostic equation (Wang 2000)

- From moving reference frame

$$\left(\frac{\partial P}{\partial t}\right)_m = \left(\frac{\partial P}{\partial t}\right)_f + \mathbf{C}\cdot\nabla P$$

- If we look for wave #1 component

$$\left(\frac{\partial P}{\partial t}\right)_{1f} = -\mathbf{C}\cdot\nabla P_s$$

PV may come from: $\left(\frac{\partial P}{\partial t}\right)_1 = HA_1 + DH_1^*$

$DH_1^* = (VA_1 + DH_1)$

- Using the least square method by minimizing

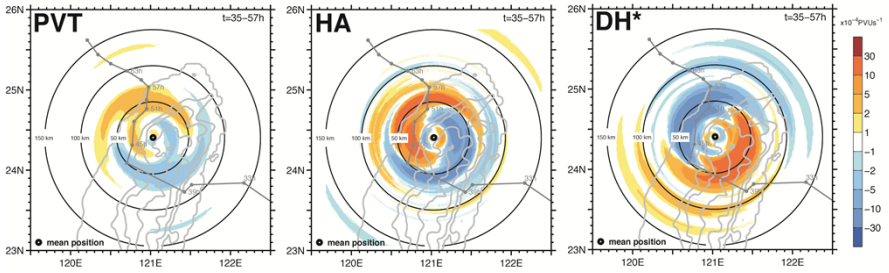
$$\sum_{i\le N}\left[\frac{\sum_{k=7}^{15}\left(c_x\left(\frac{\partial P_s}{\partial x}\right)_i + c_y\left(\frac{\partial P_s}{\partial y}\right)_i + \left(\frac{\partial P}{\partial t}\right)_{1i}\right)_k}{9}\right]^2$$

[Average from level 7-15 (1-5 km)]

PV tendency equation of baroclinic and diabatic TC motion

• **WRF ver.3.1.1 are used to simulate** westward TCs tracks with land-free **Taiwan topography** and **3 ms^{-1} uniform easterly flow**. TCs initialized as Rankine vortices.

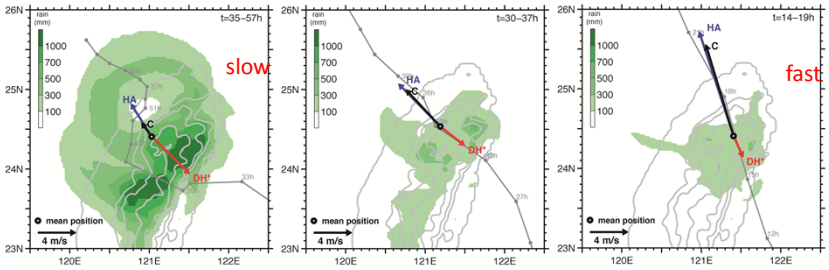
• TC landfall at about 24°N with moving speed equals to 4.6 ms^{-1} before landfall and then drops to 1.8 ms^{-1} after landfall.



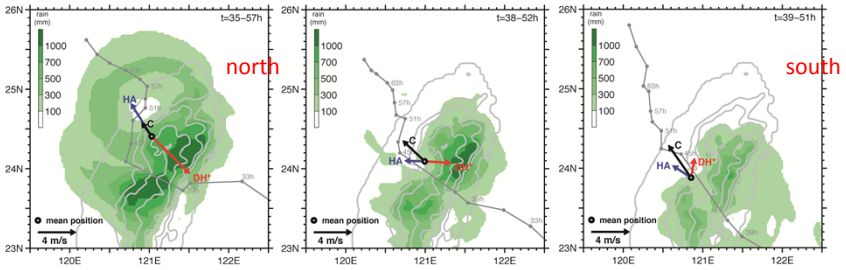
• **Potential vorticity tendency diagnostic analysis** (Wu and Wang, 2000) is used to analyze the moving speed.

• Incorporate vertical advection and diabatic heating term of PVT analysis as DH* , the result shows that DH* term tend to slow down TCs moving speed.

• **Sensitivity test of mean flow** shows that the component of DH* term is larger with small mean flow and accompanied with larger amount of rainfall.



• **Sensitivity test of landfall position** shows that landfall at higher latitude case has larger rainfall amount and slower moving speed. The moving speeds are (a)1.8, (b) 3.2 and (c) 4.2 ms^{-1}.



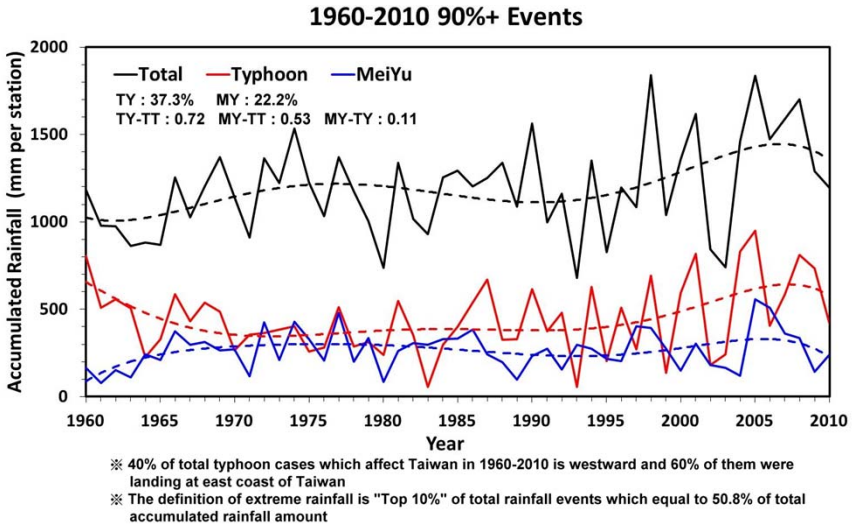
Li-Huan Hsu

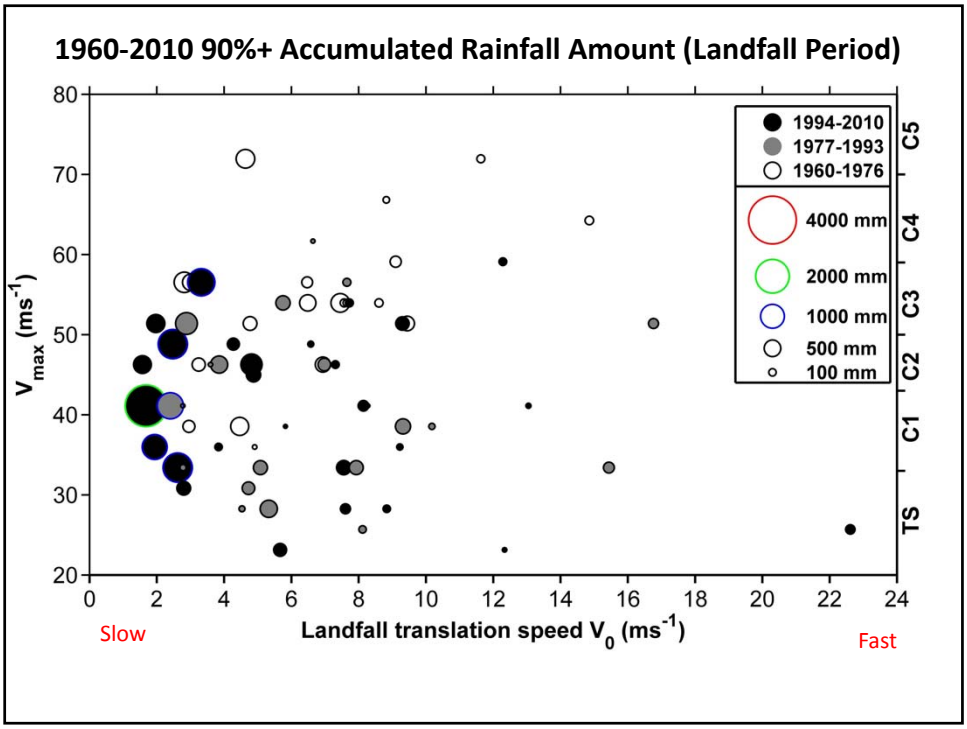
Summary

- Annual and decadal variations? 年、年代紀變化
- Typhoon + NE monsoon + mesoscale convection : major rainfall in NE of Taiwan.
- SW Monsoon + typhoon + mesoscale convection : major rainfall in SW of Taiwan （季風、颱風、中尺度與地形，夏季風颱風共伴）
- Slow movement for large rainfall
- A positive feedback of rainfall and typhoon translation speed (phase locked ppn)

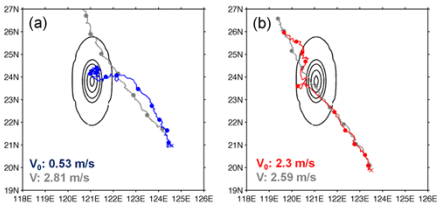
Thanks

Taiwan extreme rainfall

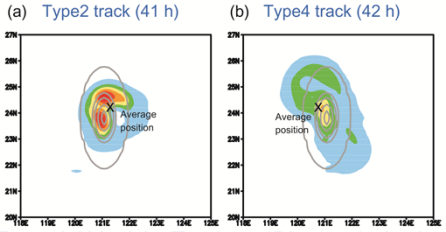




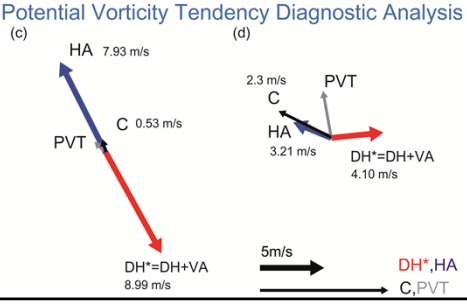
PV tendency equation of baroclinic and diabatic TC motion (WRF simulations)



Rainfall amount during landfall



Potential Vorticity Tendency Diagnostic Analysis



Wu and Wang (2000)
The wavenumber one component (asymmetric component)of Potential Vorticity tendency