(破紀錄)臺灣颱風豪雨與氣候變遷分析



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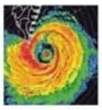
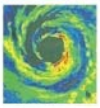
2012 Alan Berman Research Publication Award


感謝共同工作的伙伴：張智北、Fovell、王重傑、簡芳菁、蘇世顥、徐里寰、楊憶婷、陳郁涵

"Climate is what you expect, weather is what you get"

- Attributed to Robert Heinlein and Mark Twain

氣候是你的期待，極端天氣是你的日常經驗

- Chien, F.-C., and H.-C. Kuo, 2011: On the extreme rainfall of Typhoon Morakot (2009). *J. Geophys. Res.*, **116.**
- Su.-S. H., H.-C. Kuo, L.-H. Hsu, and Y.-T. Yang , 2012: Temporal and Spatial Characteristics of Typhoon Extreme Rainfall in Taiwan. *J. Meteor. Soc. Japan.*
- Wang, C.-C., H.-C. Kuo, Y.-H. Chen, H.-L. Huang, C.-H. Chung, and K. Tsuboki, 2012: Effects of Asymmetric Latent Heating on Typhoon Movement Crossing Taiwan: The Case of Morakot (2009) with Extreme Rainfall. *J. Atmos. Sci.*
- Hsu, L.-H., H.-C. Kuo, and R. G. Fovell, 2013: On the geographic asymmetry of typhoon translation speed across the mountainous island of Taiwan. *J. Atmos. Sci.*
- Chang, C.-P., Y.-T. Yang, and H.-C. Kuo, 2013: Large Increasing Trend of Tropical Cyclone Rainfall in Taiwan and the Roles of Terrain. *J. Climate*.
- Wang C.-C., H.-C. Kuo, T.-C. Yeh, C.-H. Chung, Y.-H. Chen, S.-Y. Huang, Y.-W. Wang, and C.-H. Liu, 2013: High-resolution Quantitative Precipitation Forecasts and Simulations by the Cloud-Resolving Storm Simulator (CReSS) for Typhoon Morakot (2009). *J. Hydrol.*
- Wang C.-C., Y.-H. Chen, H.-C. Kuo, and S.-Y. Huang, 2013: Sensitivity of Typhoon track to Asymmetric Latent Heating/Rainfall induced by Taiwan Topography: A Numerical Study of Typhoon Fanapi (2010). *J. Geophys. Res.*

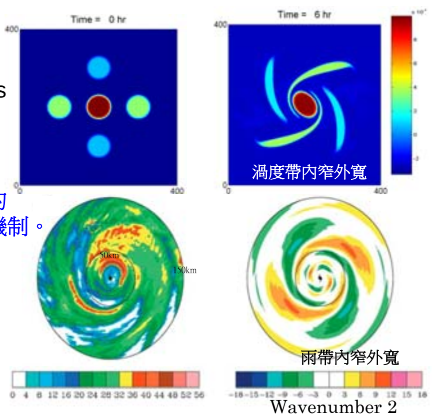
第11屆教育部國家講座

2012 Alan Berman Research Publication Award
Best publication in the Naval Research Lab.

Vorticity Dynamics
渦度動力

颱風渦漩導致雨帶
內窄外寬形變。重要的
雨帶與颱風動力渦度機制。

Radar Reflectivity
雷達回波



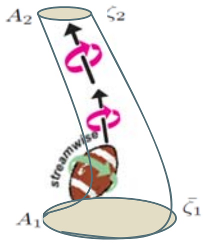
2011 IESO義大利 賽事領隊3 金 1銀

2008-2009 IESO 科學委員會主席


臺灣7次連續世界冠軍！

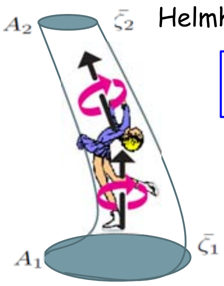
國內外颱風動力與應用數學講學

科普活動 科學推廣



Coriolis Force

Non-inertial Frame



Helmholtz Vortex Tube

$$A_1\zeta_1 = A_2\zeta_2$$

Hermann von Helmholtz (1821–1894)

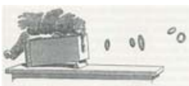
$$\nabla\cdot(\nabla\times\vec{V})=0$$

$$\nabla\cdot\vec{\zeta}=0$$

$$\int_{V_0}\nabla\cdot\vec{\zeta}\,dV=0$$

$$\int_{\partial V_0}\vec{\zeta}\cdot d\vec{A}=0$$

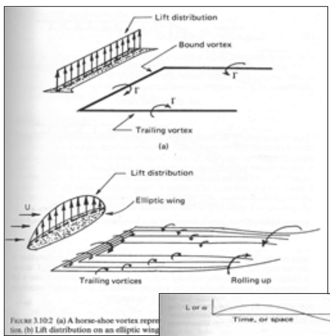
$$\oint \vec{V}_1\cdot d\vec{l}_1 = \oint \vec{V}_2\cdot d\vec{l}_2$$

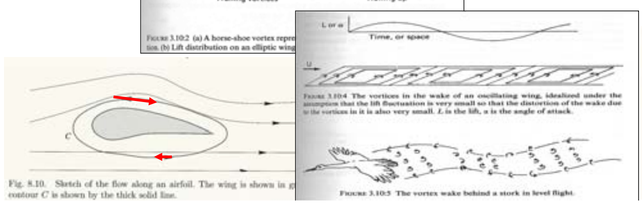


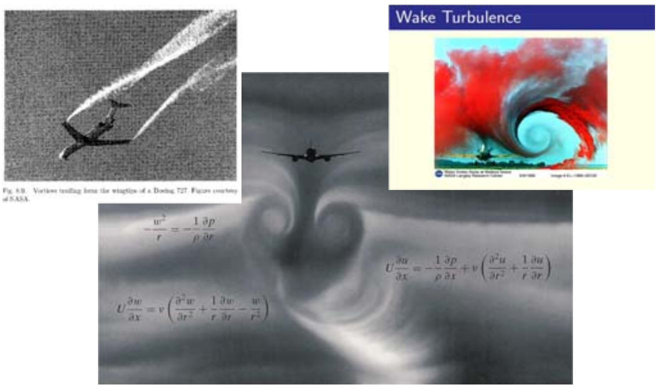
Vortex cannot terminated in the fluid interior.

Conservation of Circulation along a vortex filament.
A vortex filament can not end in a fluid, it must extend to the boundaries or form a closed path.

渦旋不中斷







A British Airways Boeing 777-200 aircraft is approaching to land at Gatwick Airport traveling at 170 kts at approximately 1800 ft. The cloud base Is 2200 ft, RH = 83%, T = 16.8, Td = 14.5, p = 1022.2 hPa, wind = 6.4 km/h.

Jupiter

Rotational period 9.84hr

Huang and Robinson 1998

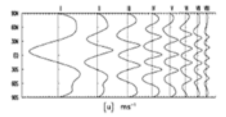


FIG. 4. Time-mean zonal-mean zonal wind profiles for cases I-VIII in Table 1 (the eight open circles in Fig. 3). Each grid on the abscissa represents 1 m s⁻¹.

The Great Red Spot

臭氧洞衛星觀測

南極渦漩將極冷空氣鎖在渦漩內，固體狀**CFC**冰晶方能破壞臭氧。

渦漩外帶狀臭氧低值區以帶狀形式出現。

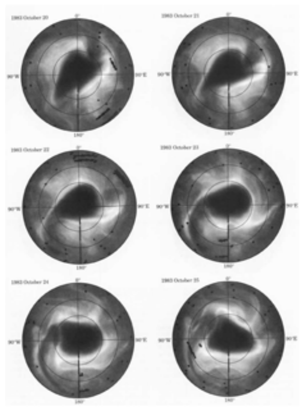


Fig.1: Daily TOMS images of total ozone in the Southern Hemisphere for six consecutive days in October 1983. Latitude circles are drawn at 40˚,60˚, and 80 ˚S. The outermost latitude is 20 ˚S.

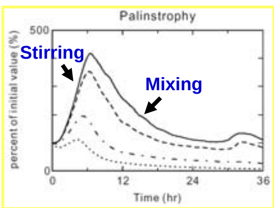
Bowmen and Mangus (1993)

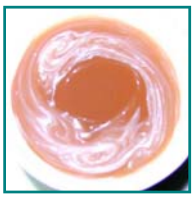
$$\frac{D\theta}{Dt} = \frac{\partial \theta}{\partial t} + \vec{V}\cdot\nabla\theta = \nu\nabla^2\theta$$

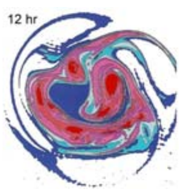
$$C = \frac{1}{2}\int \nabla\theta\cdot\nabla\theta \, dV$$

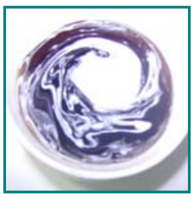
$$\frac{dC}{dt} = \int (\vec{V}\cdot\nabla\theta)\nabla^2\theta \, dV - \nu\int (\nabla^2\theta)\, dV$$

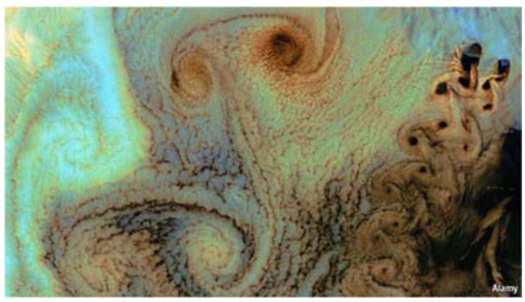
Stirring **Mixing**









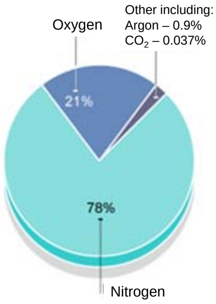


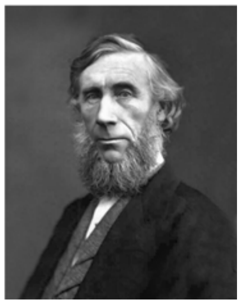
Theory points to three main mechanisms: mixing the ocean's surface layers (up to a few hundred metres) by wind; mixing of deeper layers by ocean currents; and eddies, swirls created when warm ocean currents meet cold ones, blending large swathes of the ocean 10-100km across.
Dr Salée and colleagues report in in *Nature Geoscience,* eddies suck up as much carbon as the other two mechanisms do, something most current climate models fail to account for.

Economist, 12/08/2012

Joseph Fourier (1827) – Greenhouse Effect

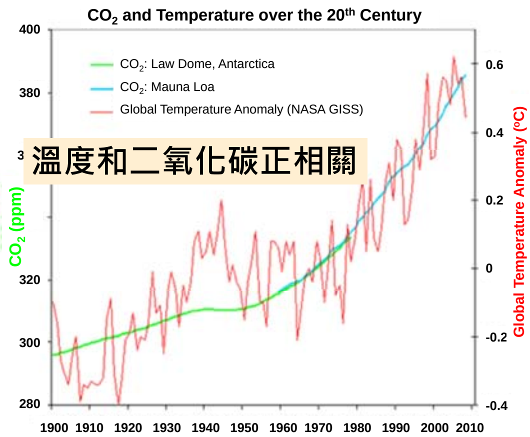
What Gases Contribute to the Greenhouse Effect?





水氣和二氧化碳是最重要溫室氣體

...ater Vapor and Carbon Dioxide were most important!



溫度和二氧化碳正相關

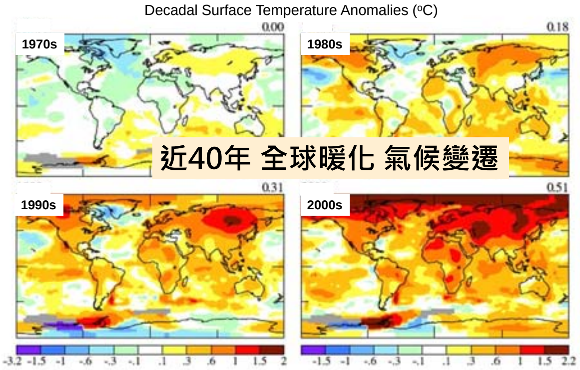
http://www.skepticalscience.com/The-CO_2-Temperature-correlation-over-the-20th-Century.html

Our planet is warmer than radiative theory would predict owing to our atmosphere

水氣和二氧化碳是最重要溫室氣體
溫室效應使地球增加32度

Greenhouse Effect Adds 32°C warming to Earth!

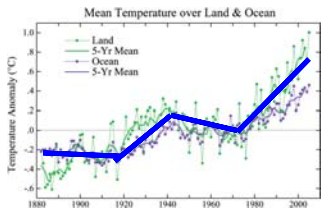
Decadal Surface Temperature Anomalies (ºC)

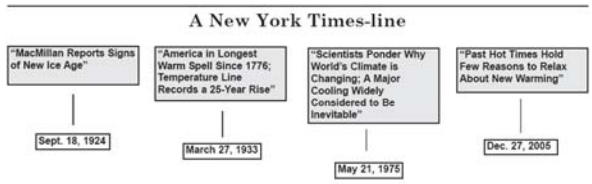


近40年 全球暖化 氣候變遷

Decadal Surface Temperature Anomalies relative to 1951 – 1980 base period

Hansen et al. (2010)

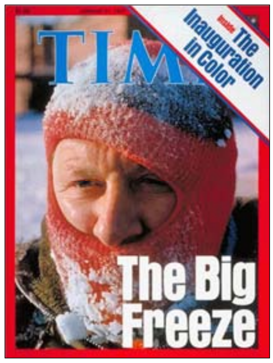




1924冷 1933 暖 1976冷 2005暖

The 1970s cooling scare

January, 1977

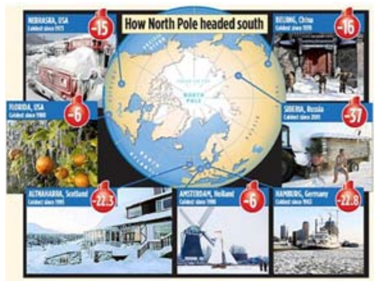


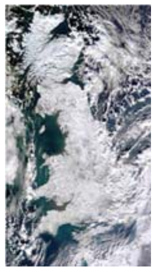
April, 2006

Global Climate Change

2010, 2011, 2012寒冬　冷相位的北極震盪

Arctic Oscillation (AO):冷相位時美東、北歐、蘇俄、及亞洲酷寒，格陵蘭暖冬。
2010年以前二十年都是暖相位，不清楚是全球暖化還是自然的十年際變異？





2010冰雪英國

FORECASTERS IN THE UNITED KINGDOM ARE SAYING THAT UPCOMING WINTER COULD BE THE MOST SEVERE THE NATION HAS EXPERIENCED SINCE CHARLES II WAS KING: (1683/84).
LONDON, DECEMBER 30, 2010

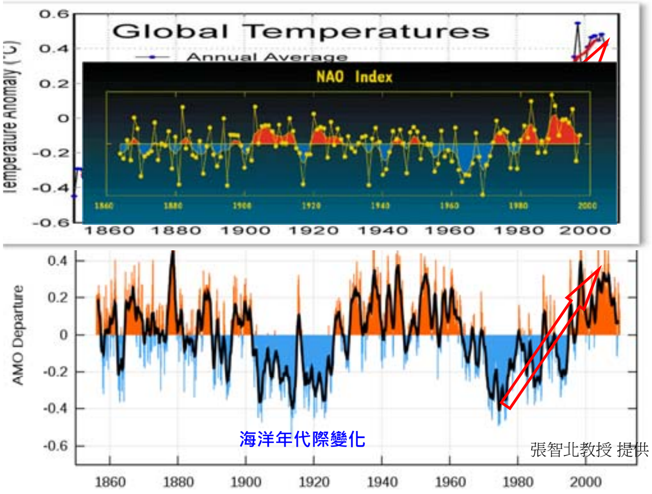
從1683-84冬天後，2011-12冬天300多年來最冷的冬天。

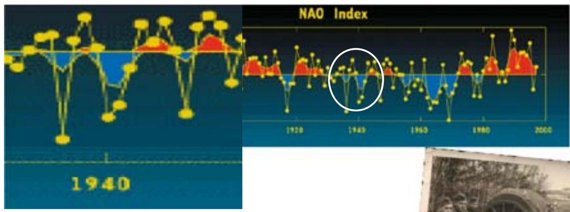
2012-2013 Winter
北半球冷吱吱 東歐凍死200人

Extreme Blizzard Conditions
Mid-West Dec. 2012

March 25 2013

2012烏克蘭最低溫零下28度　18人凍死





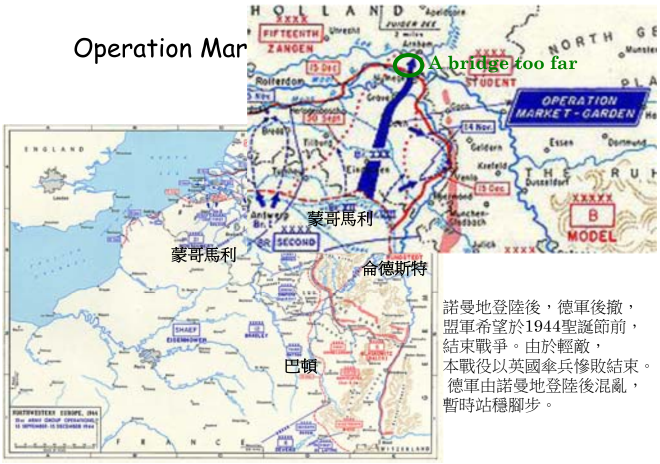
- 1939-1941連續3年冷相位，1941年希特勒進攻俄國時，接受德國氣象家的建議，認為連續三年寒冬機率小，應不會重蹈拿破崙爭俄覆轍，所以進攻俄國。
- 俄國的冬天提早了三個星期, 且在沒有聽陸軍總司令要準備冬季服裝的情形下，德軍在這段期間陣亡二十一萬人, 受傷七十萬人加上失蹤總計損失一百萬人, 在三百二十萬德軍中, 佔了三成

希特勒攻俄失敗

提早的冬天

Reference:

Operation Market Garden



諾曼地登陸後，德軍後撤，
盟軍希望於1944聖誕節前，
結束戰爭。由於輕敵，
本戰役以英國傘兵慘敗結束。
德軍由諾曼地登陸後混亂，
暫時站穩腳步。

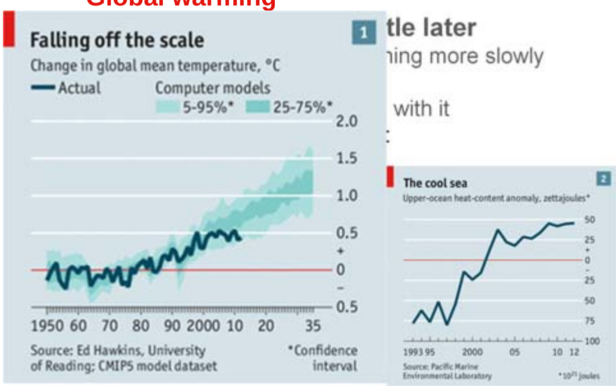
Battle of the Bulge 16 December 1944 – 25 January 1945

德軍利用風雪交加的寒冬，盟軍飛機無法出動，西線大反撲，先勝後被抑止。
因此役把東戰線預備隊用完，隔年東戰線崩潰，希特勒自殺。

美軍POW

暖化減緩?

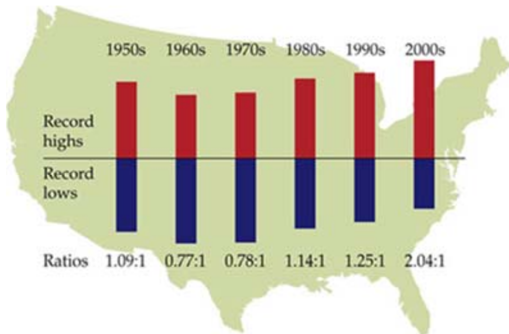
Global warming



Falling off the scale

Upper –ocean heat content

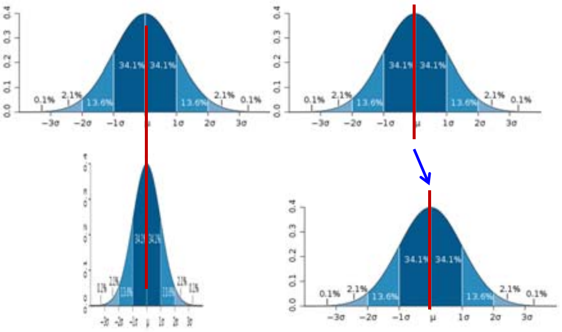
U.S. Record High Temperatures to Record Low Temperatur



A shift from ~1:1 to ~2:1

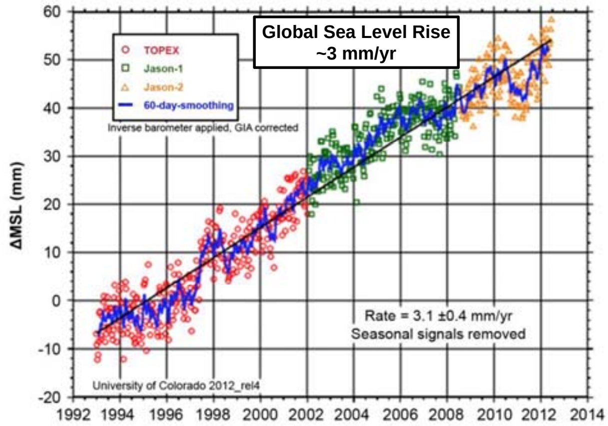
Meehl et al. (2009)

溫度平均升高　激烈天氣變多？？



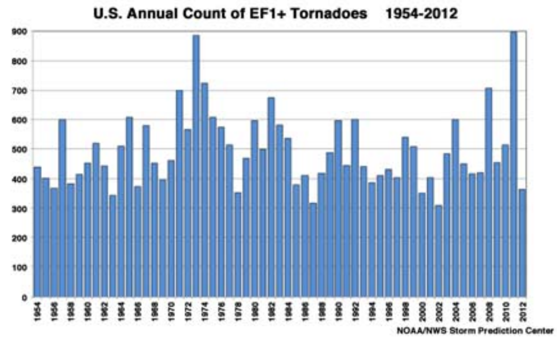
平均不變　變異度改變　　平均改變　變異度不變

平均值與變異度的關係？？ 科學大哉問！！



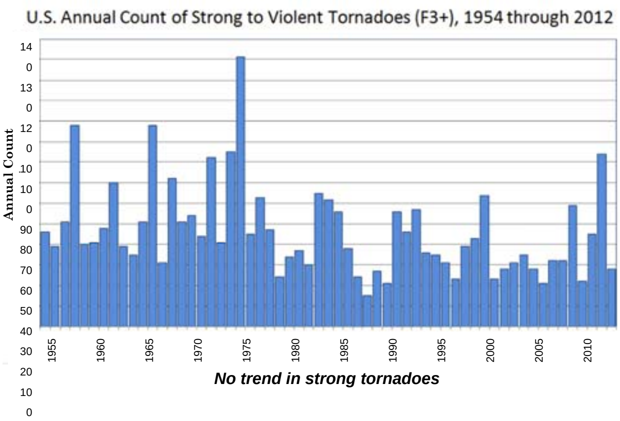
~ half owing to thermal expansion　　Nerem et al. (2010)

龍捲風總數沒有明顯趨勢變化（年代際變化）



No trend in total number of tornadoes

F3更強的龍捲風數目沒有明顯趨勢變化（略少）



No trend in strong tornadoes

Hurricane Sandy 2012

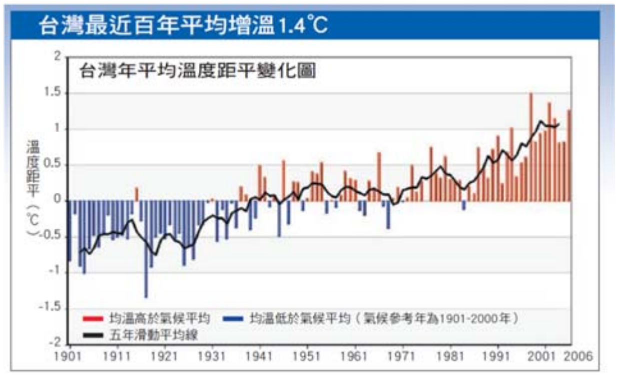
IPCC:單一事件不能歸因於全球暖化

Colorado 2013 September

Taiwan Floods 2008 SoWMEX/TiMREX

Typhoon Morakot

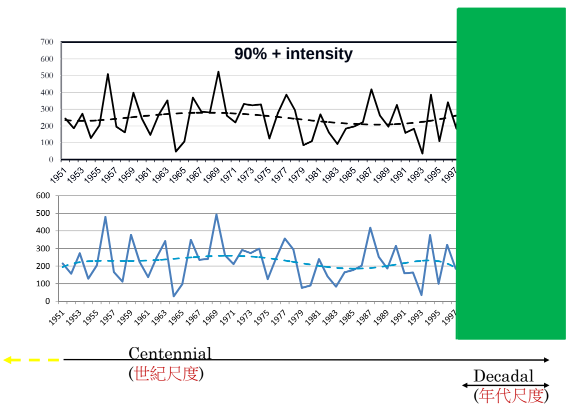
- 2009 08/05-08/10
- Most devastating typhoon to hit Taiwan during the past 50 years. (total damage about NT$110 billion)



都市熱島效應

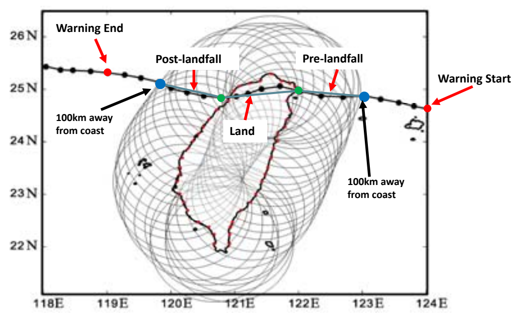
過去30年冬季風減弱寒潮變少冬天暖化非常顯著

台灣強降雨



張智北教授 提供

Westward Typhoon cases



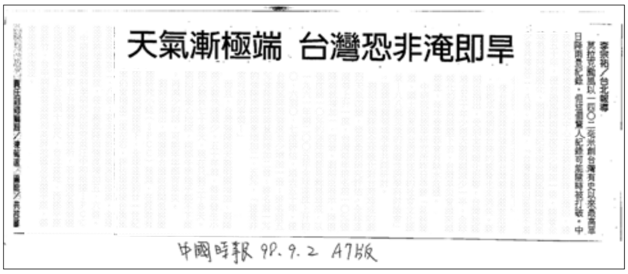
為何最近十多年臺灣颱風豪雨下不停？

Rank	Year	Typhoon Name	Rainfal (mm)
1	**2009**	**Morakot**	**8996**
2	2001	Nari	8108
3	**2008**	**Sinlaku**	**8105**
4	**2005**	**Haitang**	**5589**
5	1996	Herb	4836
6	1989	Sarah	4655
7	1960	Shirley	4637
8	**2007**	**Krosa**	**3936**
9	**2004**	**Mindulle**	**3856**
10	**2008**	**Jangmi**	**3800**
11	**2008**	**Kalmaegi**	**3763**
12	**2005**	**Talim**	**3526**

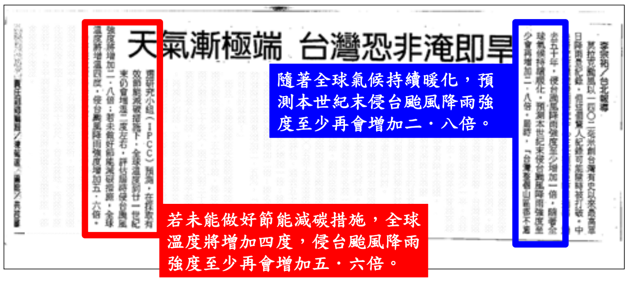
Table 1: The twelve typhoons in 1960-2011 with total rainfall over Taiwan exceeding 3500 mm during the three phases. The eight since 2004 are highlighted in boldface.

全球暖化　洋增溫　水氣變多　颱風變強　降雨變多

中國時報 September 2, 2009



中國時報 September 2, 2009



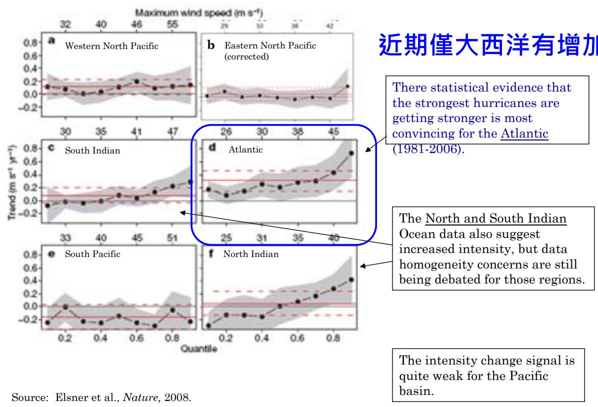
CHANGE DUE TO SURFACE WARMING

- Water vapor in the lower troposphere increases by ~7% per ˚C (by Clausius–Clapeyron equation)(**水氣～7%/K**)
- Precipitation rate increases by ~2% per ˚C (limited by change of raidative cooling)
  (**降雨～2%/K**)
  - ➔ weakening of boundary layer/troposphere mass exchange of ~5% per ˚C
  - ➔ weakening of tropical circulation ~5% per ˚C

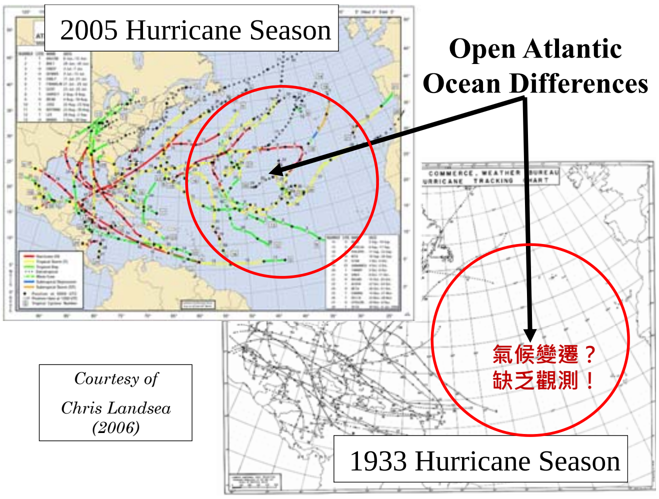
Walker Cir. Hadley Cir.熱帶環流減弱

(Held and Solden 2006, Vecchi et al. 2006)

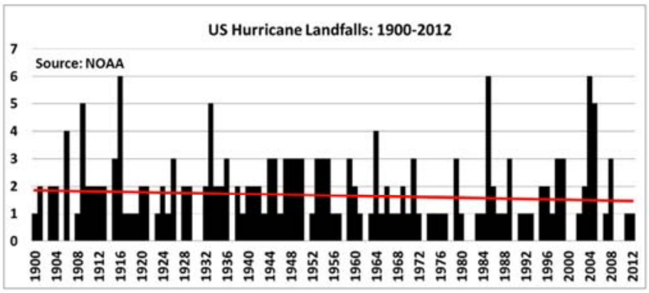
Regional Structure of Tropical Cyclone Intensity Trends



Source: Elsner et al., *Nature*, 2008.



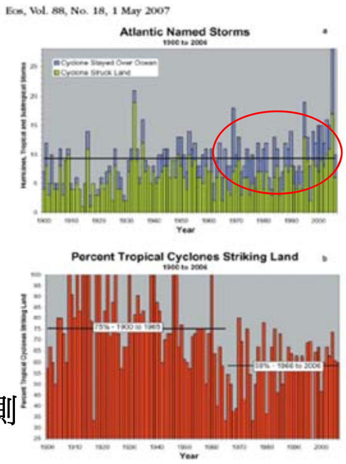
美國登陸颶風數目沒有明顯趨勢（年代際變化）



The trend does not suggest an increase in landfalls

歷史資料的不確定性！

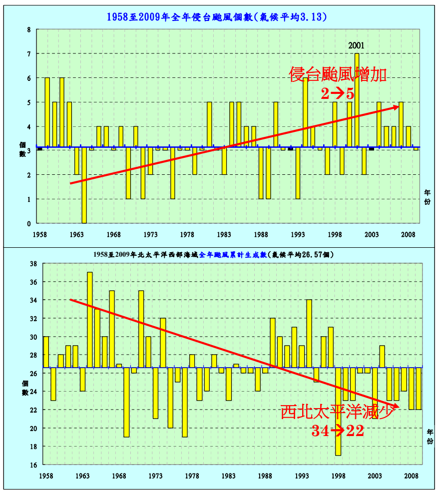
1965年後
海上颶風數目變多



登陸的颶風比例
Pre 1965 75%
Post 1965 59%

1965人造衛星觀測

全球登陸颱風數目沒有明顯趨勢（強颱減少）



侵台颱風增加，西北太平洋總數其實減少。

西北太平洋路徑：空間年代際變化。

侵台颱風增加只是近期→年代際變化。

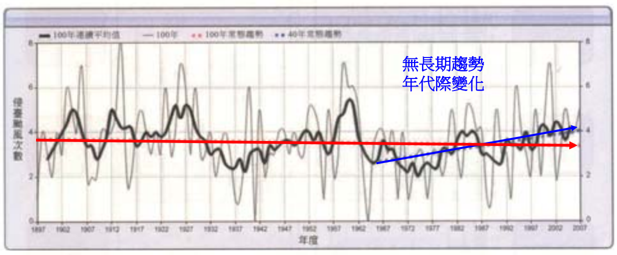
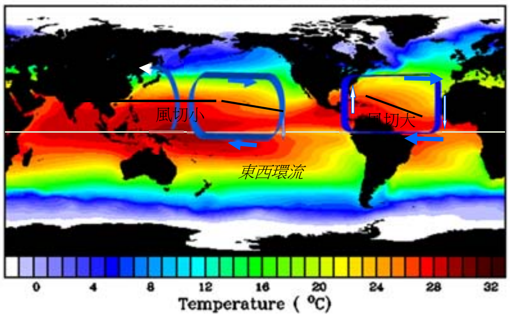


圖 2-5　臺灣地區近百年來侵臺颱風次數歷年變化圖

資料來源：李清勝、賈新興，〈颱風的長期氣候變遷〉，發表於「2008 臺灣氣候變遷」研討會（臺北：交通部中央氣象局，2008 年 8 月 25-26 日）。

全球平均海面溫度

海溫分佈可以影響風切進而影響颱風強度
上下風速度的差距愈大，風切大，颱風變弱



張智北教授 提供

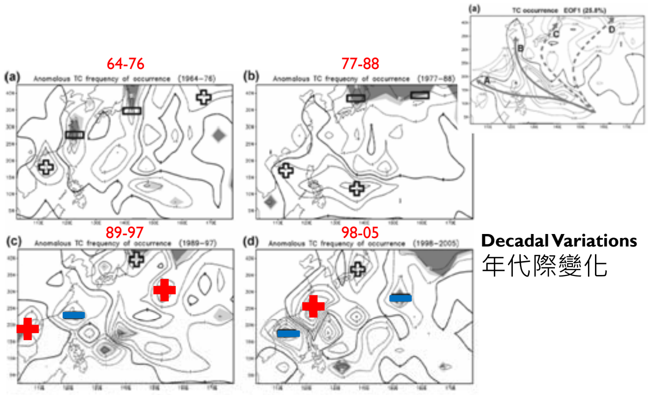


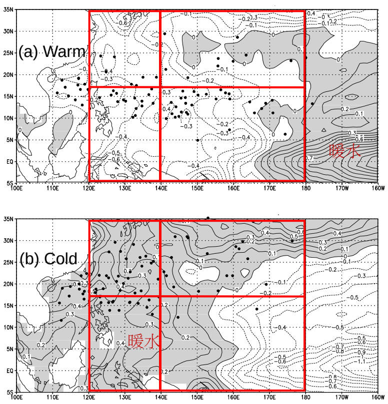
FIG. 2. Anomalous TC frequency of occurrence during the periods of (a) 1964–76, (b) 1977–88, (c) 1989–97, and (d) 1998–2005. Dark and light shadings indicate the areas with anomalies significant at the 95% and 90% confidence levels, respectively. Plus-shaped boxes (rectangular-shaped) indicate the areas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

Liu and Chan 2008

西北太平洋颱風強度和聖嬰與反聖嬰相關

El Nino
聖嬰

颱風強年



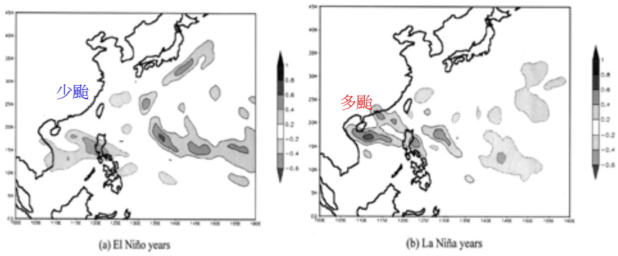
La Nino
反聖嬰

颱風弱年

(Wang and Chan 2002, J. Climate)

反聖嬰年九月或十月容易有強颱侵襲中國東南沿海

Tropical Cyclone Track Density



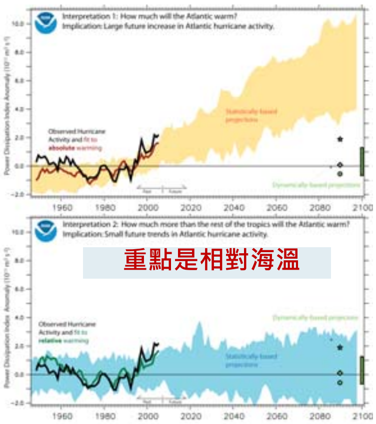
(a) El Niño years
聖嬰年 颱風平均強

(b) La Niña years
反聖嬰年 颱風平均弱

災害和颱風強度不一定有關

< ***Wu et al. 2004*** >

Two future projections of Atlantic tropical cyclone power dissipation



Source: Vecchi et al. *Science* (2008)

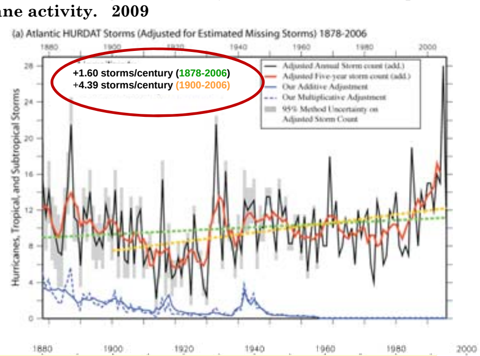
Projection 1:
Tropical Atlantic SST
Some worrisome time series…

Some alternative perspectives…

Projection 2:
Tropical Atlantic
SST Relative to Tropical Mean SST

新的模式理論：百年後強颱增加2-11%，雨量多20%，但弱颱減少。

It is premature to conclude that human activity--and particularly greenhouse warming--has already had a discernible impact on Atlantic hurricane activity. 2009



明顯年代際變化　目前無法證實和暖化有關

Decadal Variation

Trend from 1878-2006: Not significant (p=0.05, 2-sided tests, computed p-val ~0.2)
Trend from 1900-2006: Is significant at p=0.05 level

Source: Vecchi and Knutson, J. Climate, 2008.

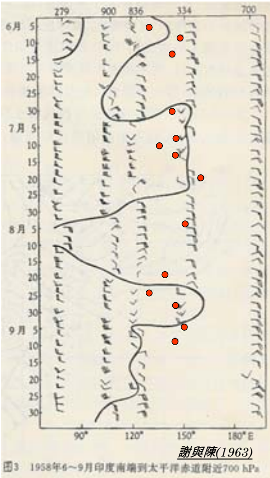
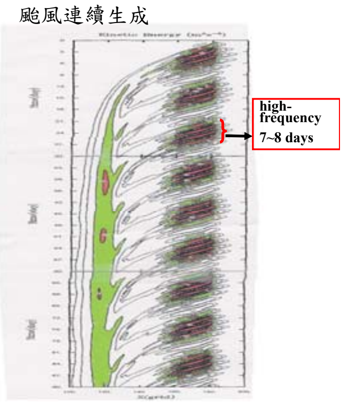


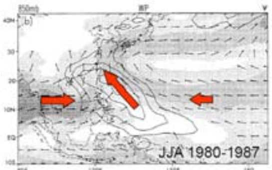
图3 1958年6~9月印度南端到太平洋赤道附近700 hPa 东西风分界线与台风发生的关系

Nonlinear wave accumulation
颱風連續生成

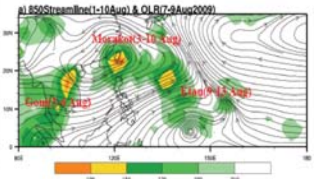


Kuo et al . 2001

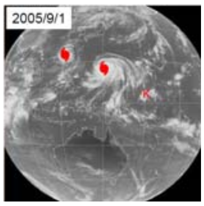
西北太平洋颱風連續生成

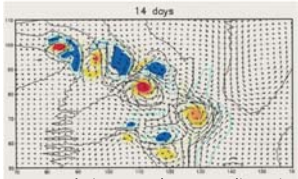


Lau and Lau (1990)

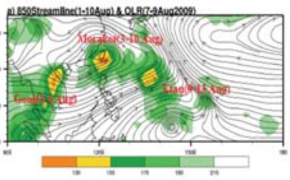


Hong et al. (2010)

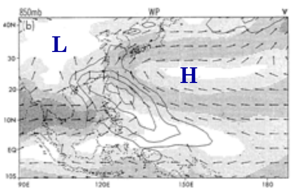




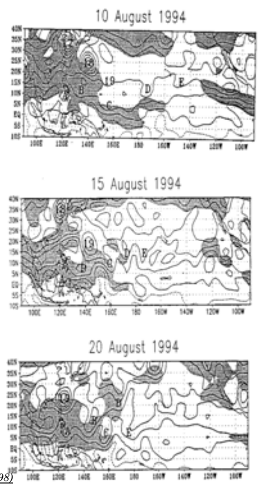
Wave accumulation + Rossby energy dispersion
Kuo et al. (2001)



Hong et al. 2010



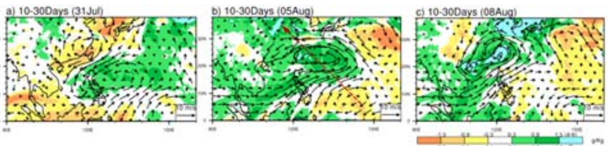
Lau and Lau, 1990 JJA 80-87



Sobel and Bretherton(1998)

Typhoon Morakot

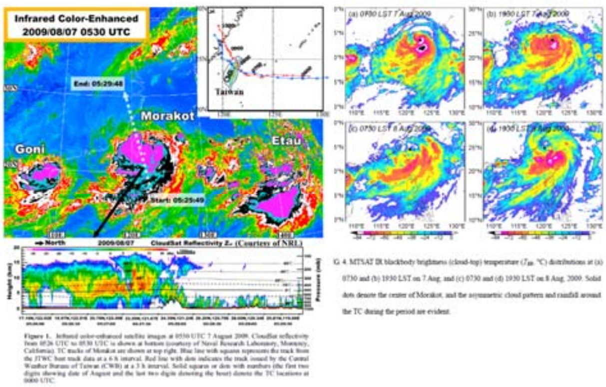
- The propagation direction of submonthly wave pattern is **from the southeast toward the northwest** across WNP in early August.



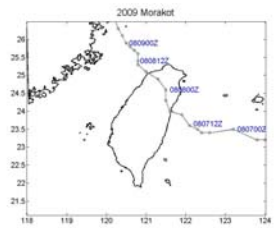
- Morakot was subjected to an **easterly background flow** when it approached Taiwan on 5 Aug but relatively **weak** ambient flow near and shortly after its **landfall** in Taiwan on 8 Aug.

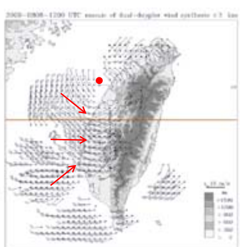
(Hong et al. 2010)

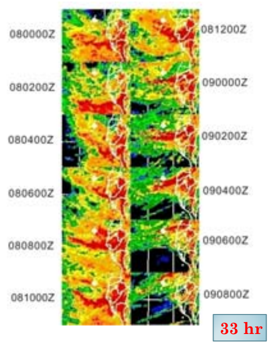
Highly Asymmetric Rainfall Pattern

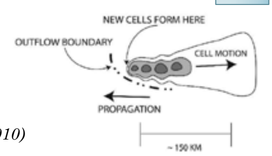


(Chien and Kuo 2011; Wang et al. 2012)



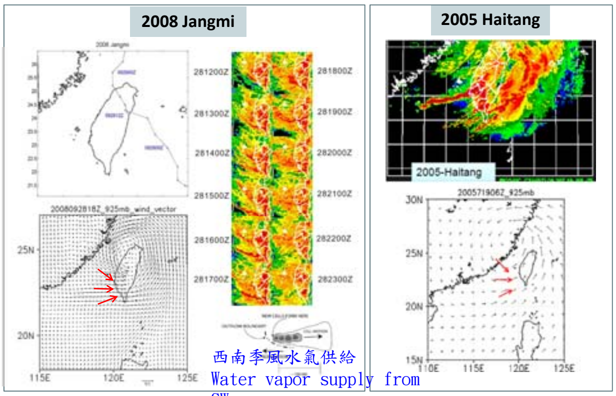




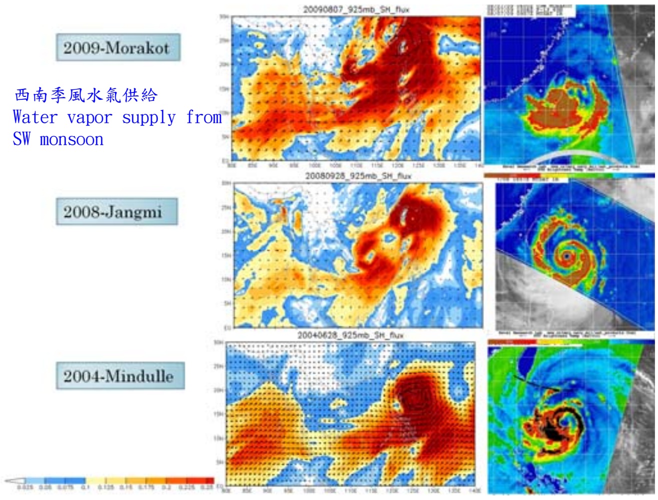


Jou et al.(2010)

Typhoon Morakot is not a special case.



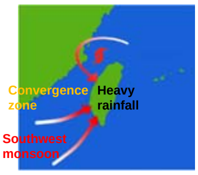
西南季風水氣供給
Water vapor supply from SW monsoon



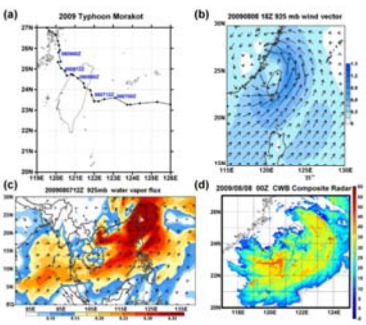
西南季風水氣供給
Water vapor supply from SW monsoon

Typhoon rainfall in Taiwan

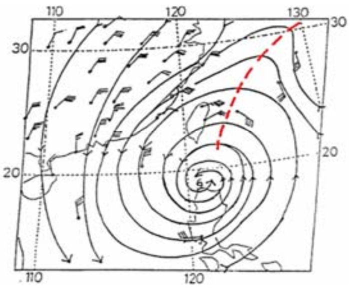
- Typhoon translation speed
- **Typhoon interaction with Monsoon flow**
- Rainfall phase locked with topography



Typhoon Morakot (2009)
- Interaction with southwest monsoon flow



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 surg

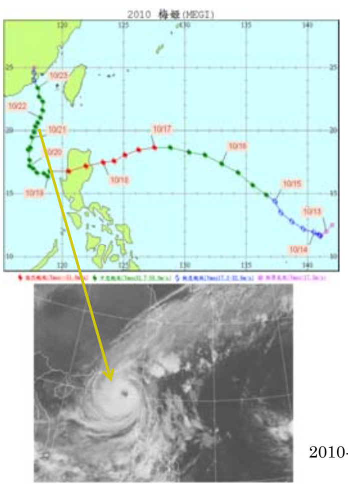
Typhoon Lynn (1987)

Flood in Taipei city

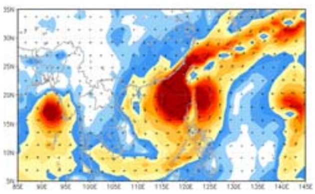
Typhoon Megi (2010)

颱風位於巴士海峽，北部東北部持續降雨

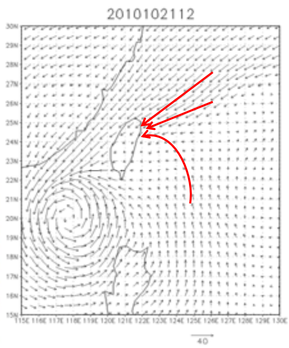
中尺度對流系統與地形作用



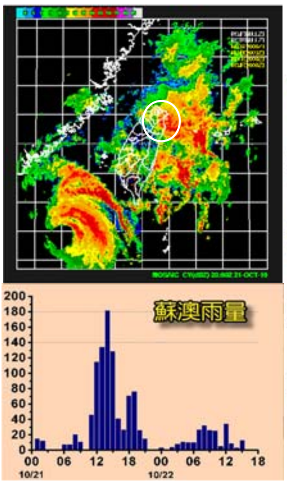
2010-10-21-20 IR

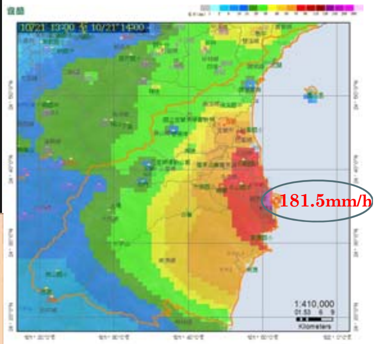


2010/10/21 12Z Typhoon Megi



Typhoon Megi (2010)





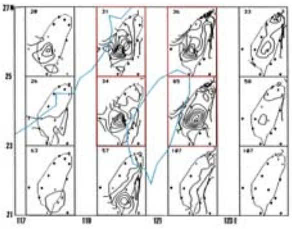
24至36小時前有能力預測
數十至近百公里豪大雨區域
（地形鎖住效應）

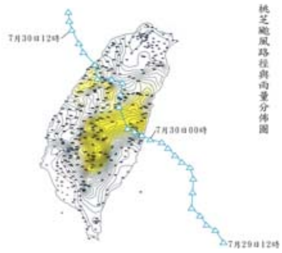
數小時與數十公里範圍
中小尺度的氣象預報
仍是挑戰

2001年潭美颱風，無預警
情形下，中尺度對流，
五小時下355mm豪雨，
重創高雄市, 2008年卡玫基颱風重創中南部；
2010年凡那比颱風再次6小時重創高雄

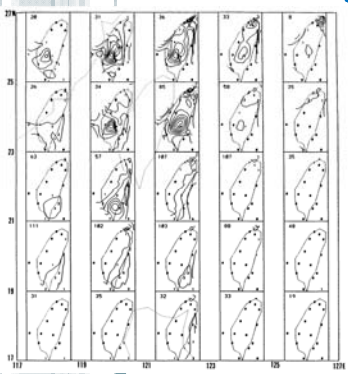
24-72小時路徑預報（颱風
來不來？）

水門關閉時機
停班停課與停止活動
考試舉行與否

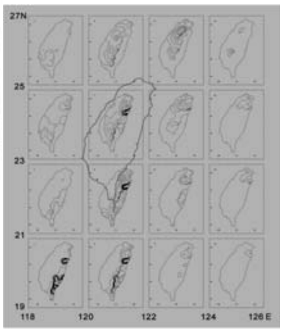




TC rainfall climatology over Taiwan



Chang et al. (1993)
82 typhoons, 22 surface stations



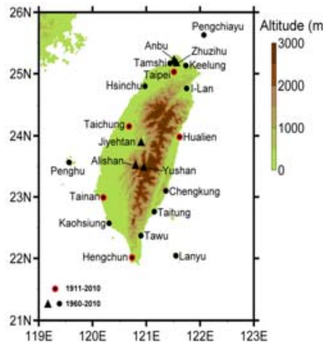
Cheung et al. (2008)
62 typhoons, 371 rain gauges

Maximum in windward side and central mountain area

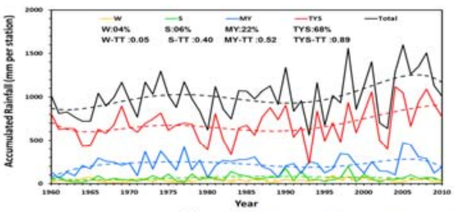
Taiwan Typhoon Rain Intensity

- 21 hourly stations 1960-2011
- 84 landfalling typhoons (all seasons)
- Rainfall affected by
  Interaction with Terrain
  Interaction with Monsoon

降雨受地形與 季風影響
Topography
+ Monsoon flow



1960-2010 95% Extreme Rainfall (9mm/hr)

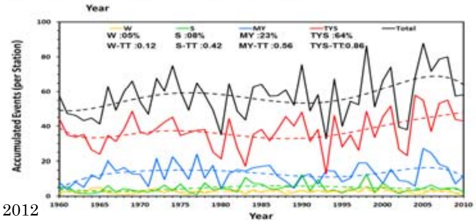


TC rainfall increase in the last decade

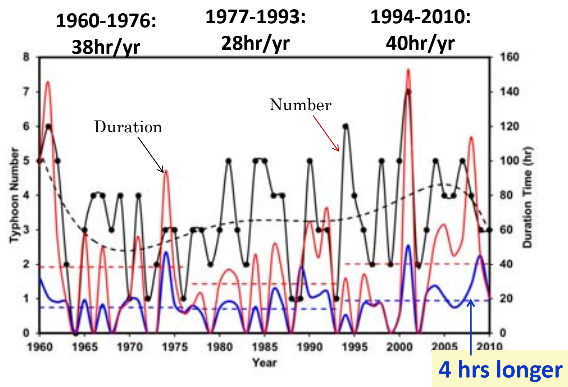
累積颱風雨增加

Frequency increase

颱風劇烈降雨時間增加



Su et al. 2012



年際與年代際變化
Large annual variation + Decadal change

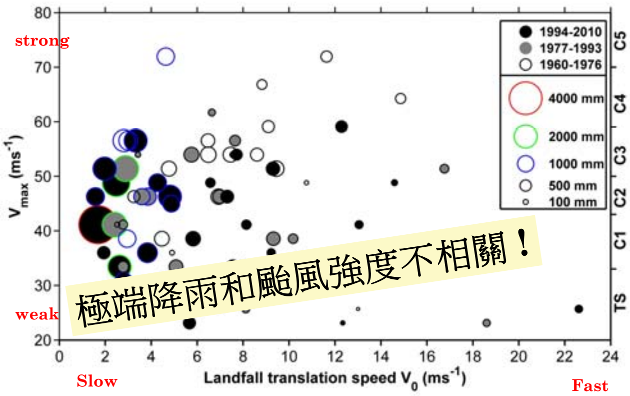
Su et al. 2012

Why most of the top rain storms occurred in the last decade ?

Rank	Year	Typhoon Name	PR	OL	EX	Total (h)	Rainfall (mm)	Track type
1	2009	Morakot	12	15	18	45	8996	CWB 3 (C)
2	2001	Nari	10	51	14	75	8108	CWB Special
3	2008	Sinlaku	16	10	22	48	8105	CWB 2 (N)
4	2005	Haitang	11	9	12	32	5589	CWB 3 (C)
5	1996	Herb	5	7	4	16	4836	CWB 2 (N)
6	1989	Sarah	5	20	13	38	4655	CWB 3 (C)
7	1960	Shirley	3	11	10	24	4637	CWB 2 (N)
8	2007	Krosa	12	1	10	23	3936	CWB 2 (N)
9	2004	Mindulle	16	18	7	41	3856	CWB 6
10	2008	Jangmi	4	13	8	25	3800	CWB 2 (N)
11	2008	Kalmaegi	8	10	5	23	3763	CWB 2 (N)
12	2005	Talim	4	9	4	17	3526	CWB 3 (C)

Chang et al. 2013

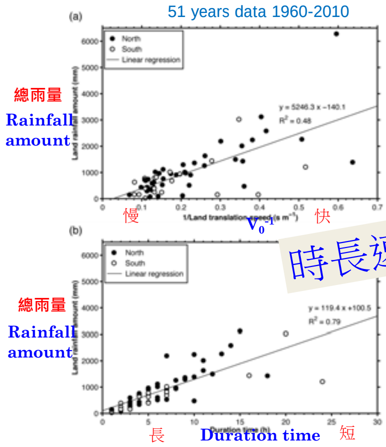
1960-2010 90%+ Rainfall Events (Landfall Period)



Su et al. 2012

Slow storms are with heavy rainfall amount

51 years data 1960-2010



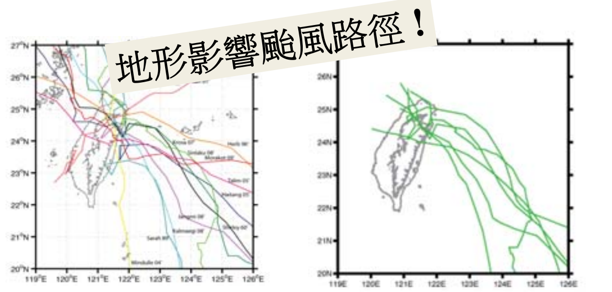
Slow movement and longer duration for larger rainfall

時長速慢降雨大！

Hsu et al. 2013 JAS

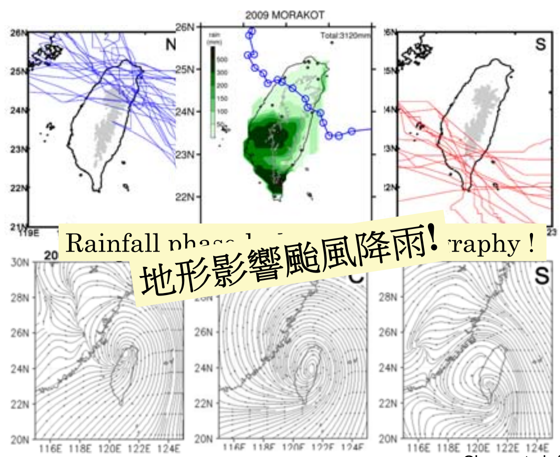
Tendency to turn towards island on approach. Current explanations involve mainly physical impacts of topography

地形影響颱風路徑！



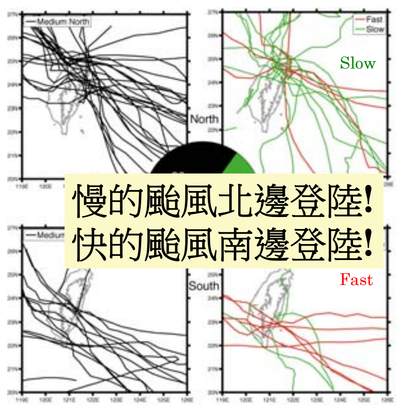
Top rain storms

Subset of slow northern landfalling storms



Chang et al. (2013)

Asymmetric distribution of typhoon translation speed overland



Slowest group at north
Fastest group at south

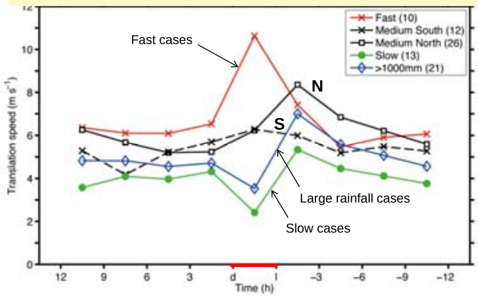
Speed criteria :
61 continuous track typhoons mean translation speed (6.2 m/s)± 1 std. (2.9 m/s)

- 77 % of slow moving storms making landfall on northern Taiwan (10/13).
- 60 % of fast cases making landfall on southern Taiwan (6/10).

Hsu et al. 2013 JAS

Speed reduction of 3m/s for slow TCs after landfall

慢的颱風登陸後變得更慢 3m/s!

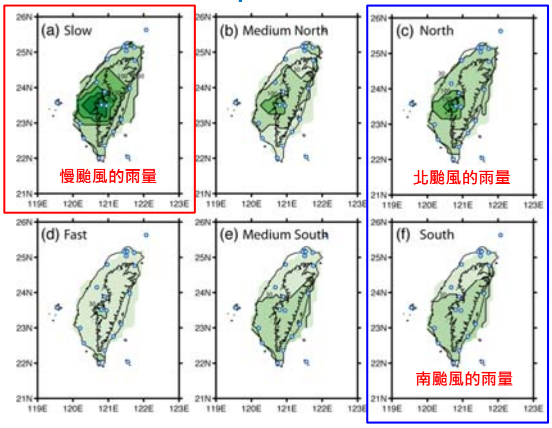


- **Slow cases** and **large rainfall cases** **slow down** after landfall.
- **Fast cases** speed up after landfall.

Hsu et al. 2013 JAS

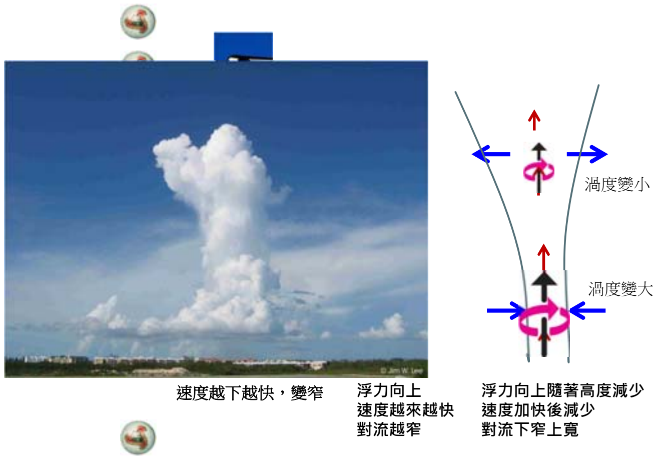
Composite Rainfall

地形影響



渦旋圓周運動 內縮加快旋轉

角動量守恆 外放旋轉變慢

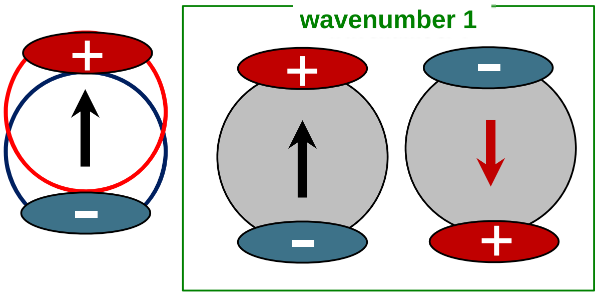


速度越下越快，變窄

浮力向上
速度越來越快
對流越窄

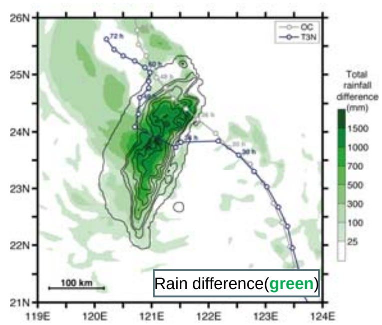
浮力向上隨著高度減少
速度加快後減少
對流下窄上寬

Wavenumber 1 & motion



WN1 PV tendency produced by TC motion
TC motion caused by WN1 PV tendency

WRF model simulation



small part of domain

- **Modified WRF Ver. 3.1.1** (Fovell and Su, 2007; Fovell et al., 2009,2010; Cao et al., 2011)
- 1500 km x 1500 km domain
- 5 km horizontal resolution, 35 vertical levels
- Uniform 3 m/s easterly flow
- Lin et al. microphysics scheme
- Jordan's (1958) Caribbean hurricane season sounding with fixed SST=29˚C
- Bogused Rankine Vortex to SE of Island
- Taiwan topography (land free)
- Water Crafted Mountain

PV tendency diagnosis for baroclinic vortex motion

$$\frac{\partial P}{\partial t} = \Lambda_1 \left[-\vec{V}_h \cdot \nabla P - w\frac{\partial P}{\partial z} + \mathrm{DH} + \mathrm{R} \right]$$

Wavenumber 1 (WN1) HA VA

$$\mathrm{DH} = \frac{1}{\rho}\left[(\zeta + f)\frac{\partial Q}{\partial z} + \left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right)\frac{\partial Q}{\partial y} + \left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right)\frac{\partial Q}{\partial x} \right]$$

Vertical average of WN1 PV tendency

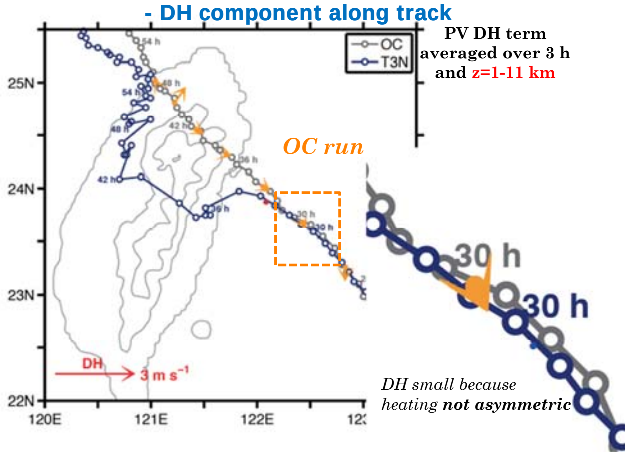
Symmetric PV advection driven by vertical WN1 PV tendency

$$\frac{\partial P}{\partial t} = -C \cdot \nabla P_s = -Cx\frac{\partial P_s}{\partial x} - Cy\frac{\partial P_s}{\partial y}$$

By least square method

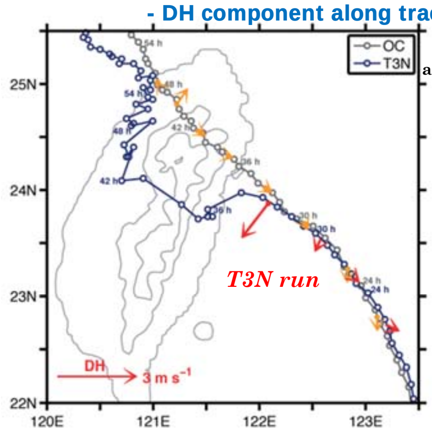
(Wu and Wang 2000; Cao et al. 2011; Hsu et al. 2013)

PV tendency analysis on TC motion - DH component along track



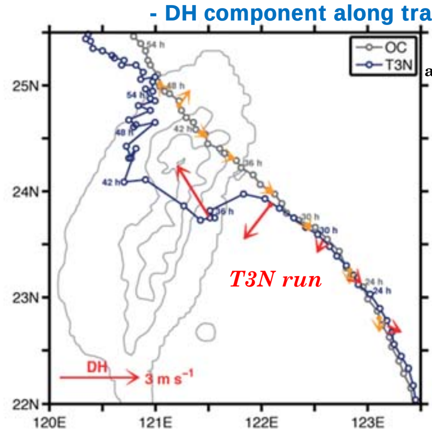
PV DH term averaged over 3 h and z=1-11 km

PV tendency analysis on TC motion - DH component along track



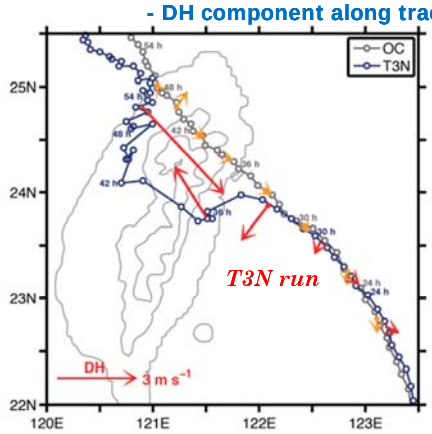
PV DH term averaged over 3 h and z=1-11 km

PV tendency analysis on TC motion - DH component along track



PV DH term averaged over 3 h and z=1-11 km

PV tendency analysis on TC motion - DH component along track



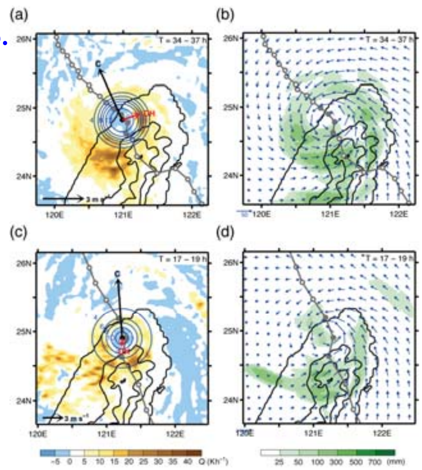
PV DH term averaged over 3 h and z=1-11 km

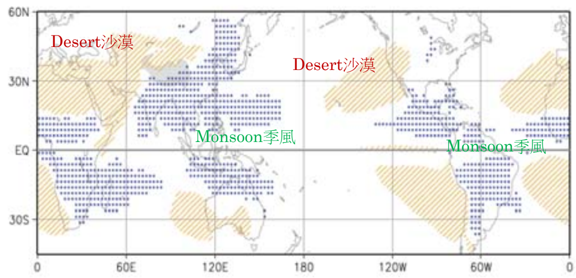
3 m/s Slowdown

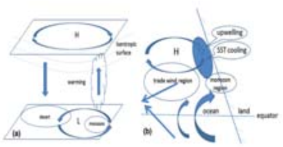
FAST N Exp.

N 5 m/s

N 10 m/s



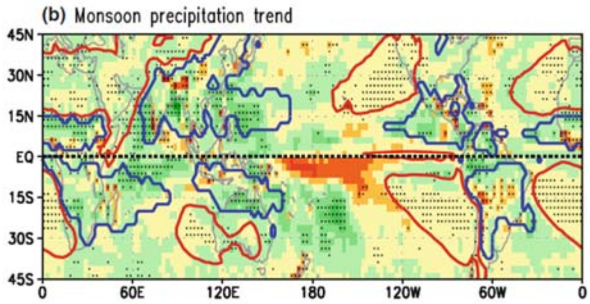




Monsoon 季風
Summer SH(NDJFM) NH(MJJAS)
Summer – Winter ppn > 2mm/day
Summer ppn .55% of Annual ppn
Desert 沙漠
Summer ppn < 1mm/day

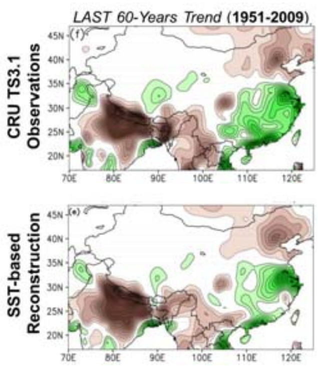
Wang et al. 2012

Walker, Hadley Circulations enhanced
Wet-get-wetter and dry-gets-drier by monsoon-desert coupling
Not the same as the global warming signal Walker Circulation weaken by water vapor increase



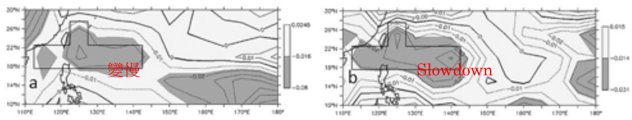
(1979-2008) Wang et al. 2012

South-Flood North-Drought (SFND)



南澇北旱

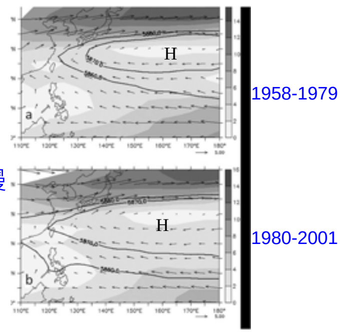
Nigam and Zhou (2012)
NTU International Science Conference on Climate Change

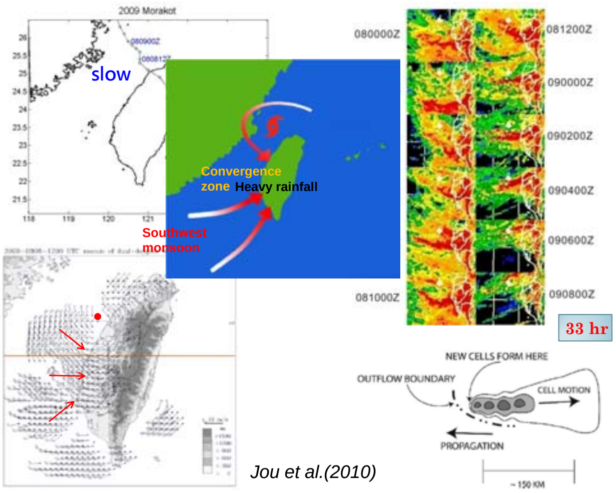


Expansion of Sub-High
Slowing down of steering near Taiwan
副熱帶高壓範圍變大
西南季風加強
台灣附近過去30年駛流變慢

Have steering flows in the western North Pacific and the South China Sea changed over the last 50 years?

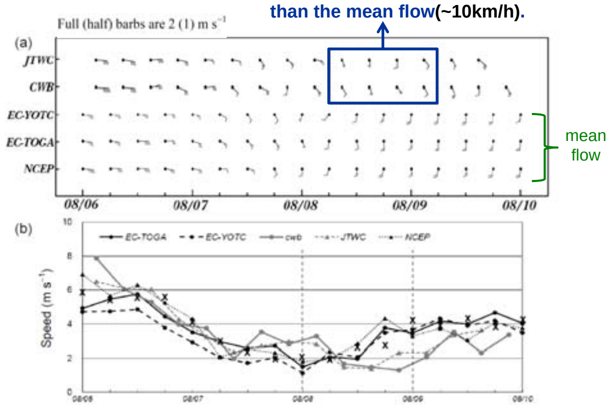
Chu et al. 2012 GRL





Jou et al.(2010)

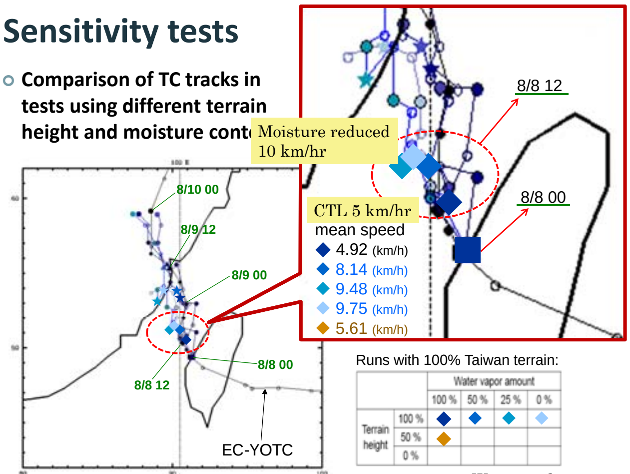
Morakot (~5km/h) clearly moved slower than the mean flow(~10km/h).



(Chien and Kuo 2011; Wang et al. 2012)

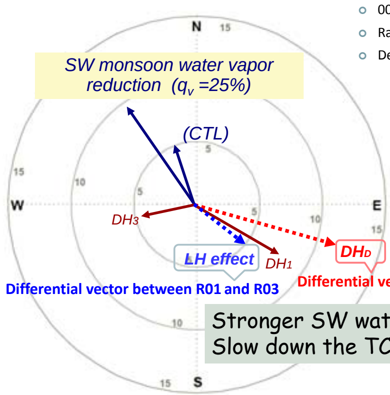
Sensitivity tests

- Comparison of TC tracks in tests using different terrain height and moisture cont[ent]



Wang et al. 2012

PV tendency diagnosis for baroclinic vortex motion

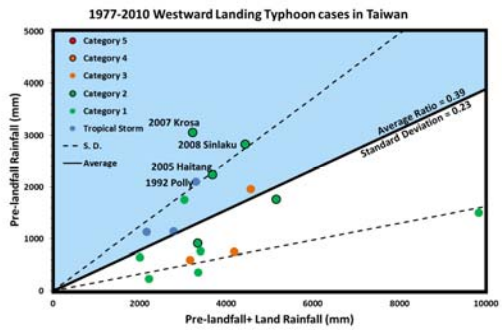


- 0000-1200 UTC 8/8 (12h)
- Radius : 330 km
- Depth : 3-7 (3-5.5) km)
  - **CTL**: mean motion vector with 100% water vapor
  - **25%**: mean motion vector with 25% water vapor
  - **DH1** : diabatic heating with 100% water vapor
  - **DH3** : diabatic heating with 25% water vapor

Stronger SW water vapor transport
Slow down the TC motion by DH effect

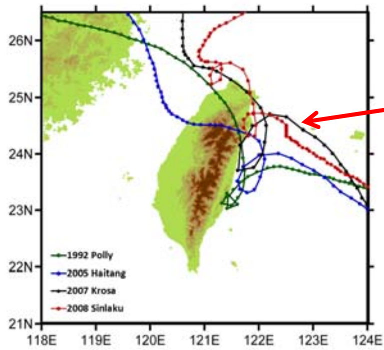
Y. H. Chen Master thesis 2013

Pre-landfall dominate



Pre-landfall + Land rainfall amount > 2000mm
Pre-landfall rainfall > 1.5 (Land rainfall)

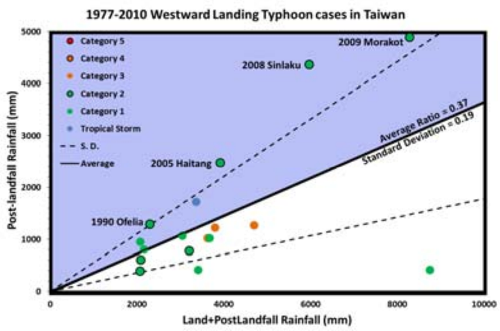
Pre-landfall dominate



Looping track before Typhoon landfall

- Topographic Rossby effect (Kuo et al.,2001)
- Channel effect (Jian and Wu, 2007)
- 2nd vortex center (Yeh et al., 2011)

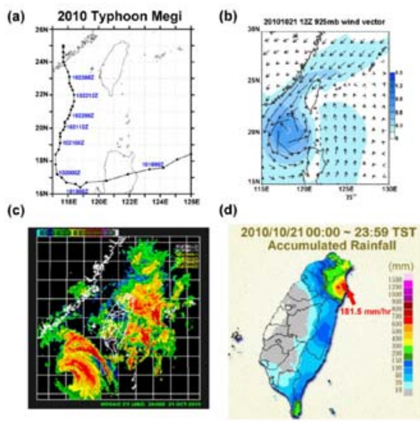
Post-landfall dominate

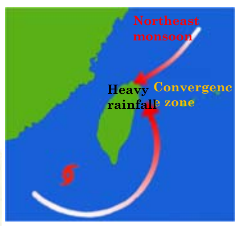


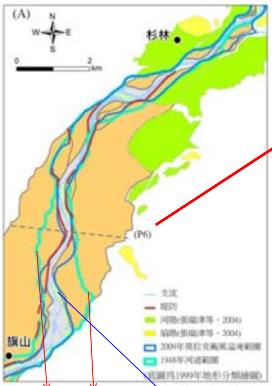
Post-landfall + Land rainfall amount > 2000mm
Post-landfall rainfall > 1.2 (Land rainfall)

Typhoon Megi (2010)

Distant Rainfall







1948年河道更寬廣

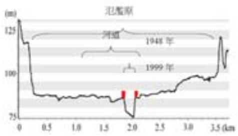


圖 5. 旗山溪旗山至杉林間莫拉克颱風洪水溢淹範圍、颱風前河道範圍和 1948 年河道範圍之疊合圖。剖面 P6 位置以灰色虛線標示於圖(A)中。堤防資料主要判釋自各年度影像，並參考第七河川局(2009)旗山溪河川構造物分布位置圖而繪製。

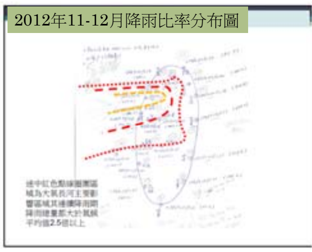
Debris flow and flooding triggered by Typhoon Morakot and their implications, Nanzishian Stream, southern Taiwan

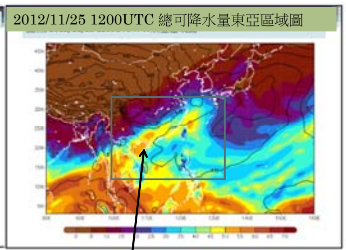
1948河道

2009莫拉克淹水溢淹

2010

ATMOSPHERIC RIVERS(大氣長河)
周仲島教授(科學人)

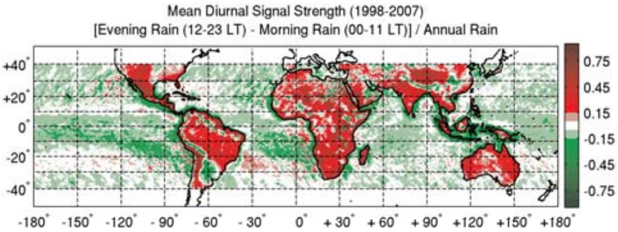




周仲島(2013)

台灣北部降雨總量大於氣候平均值2.5倍以上

Jet and water vapor
水氣輸送



- Maximum rainfall over land during the afternoon/evening in response to solar heating of the surface and a morning maximum over the oceans.
- Exceptions over land and ocean.
- Downstream of the Rocky Mountains, the Andes, and the Tibetan Plateau.

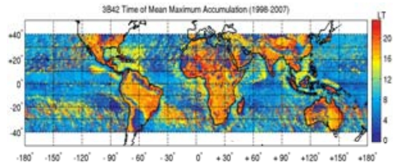
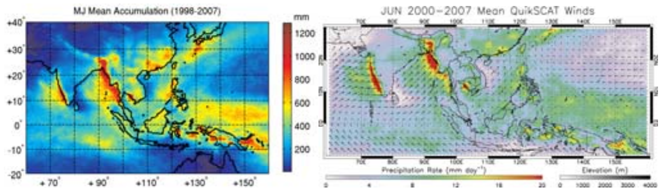
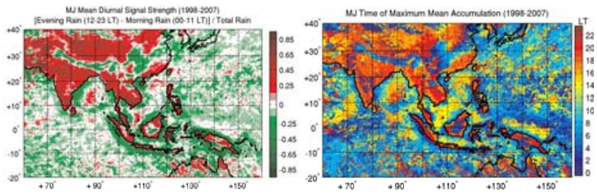


Figure 3. Time of maximum rainfall (LT) for ten years (1998-2007) using TRMM 3B42 data.



- Coastal rainfall maxima occur in the presence of strong southwesterly monsoon flow.



- The diurnal cycle appears to play some role in the heavy rainfall off the west coasts of India and Myanmar. However, there are some notable exceptions over Bay of Bengal and South China Sea.

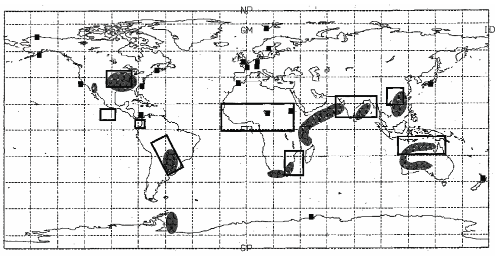
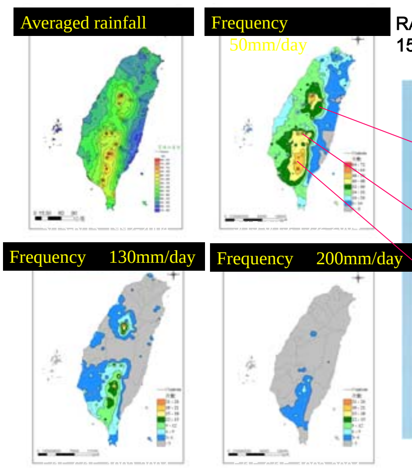
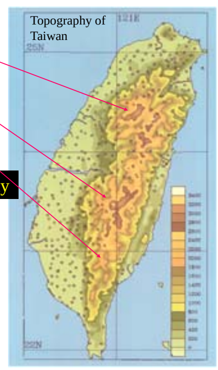


Figure 11. Regions where low-level jets are known or suspected to occur with some regularity (shaded) and where mesoscale convective complexes are know to occur frequently during the summer (open boxes). Squares denote locations where low-level jets have been occasionally observed. (from Stensrud 1996)

- Topography plays an important role in a number of these jets.
- Many of the areas of significant mesoscale convective complex (MCC) activity are colocated with low-level jets.
- Many of these jets vary diurnally and hence contribute to a diurnal variation in convective activity.

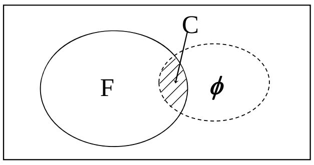
RAINFALL STATISTICS OF MAY 15-JUNE 15, 1992-2004.





(From Prof. Ben J.D. Jou)

QPF（定量降水預報） 現況



T得分之概念示意圖。F為預報定量降水的範圍，
ϕ為觀測到的定量降水範圍，C為正確預報範圍

T得分： $TS = \dfrac{C}{F+\phi-C}$ 前估： $PF = \dfrac{C}{\phi} = \dfrac{T(1+B)}{1+T}$

偏倚： $B = \dfrac{f}{\phi}$ 後符： $PA = \dfrac{C}{F} = \dfrac{T(1+B)}{B(1+T)} = \dfrac{\phi}{B}$

中央氣象局豪（大）雨預報能力

	TS	前估	後符
颱風	0.60	0.68	0.85
梅雨	0.17	0.20	0.57

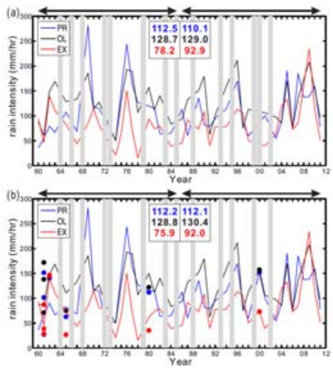
- 綜觀尺度過程 V.S. 中尺度過程
- 梅雨季豪（大）雨：對中尺度過程缺乏了解

陳泰然老師

最近25年，颱風離台後，因西南夏季風變強，颱風降雨強度變強。
過去50年，登陸前與登陸期間，颱風降雨強度無明顯變化，地形控制。

強颱風
降雨強度

弱颱風
降雨強度



3 Track Phases:
PRe-landfall,
Over**L**and,
EXit

Chang et al. 2013

”氣候科學是本世紀的重大問題，數學模式使氣候科學成為實驗科學，觀測分析提供電腦數學實驗所必須有的驗證。” 林長壽 張智北 郭鴻基

“除了有朝未來單一方向增加或減少的趨勢外，也有相當明顯的多年代類似週期性的震盪，很可能是自然變化所產生。此二者在幾十年的年代尺度內不易分辨，可能相互加強或相互抵銷。”

電波望遠鏡陣列

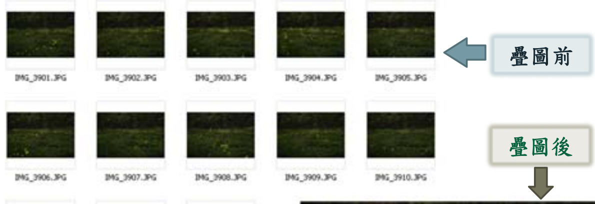
美國新墨西哥州之極大陣列VLA(Very Large Array)電波望遠鏡，共二十七座。

- 同時利用陣列中相距甚遠的望遠鏡進行觀測，可提升資料解析度。

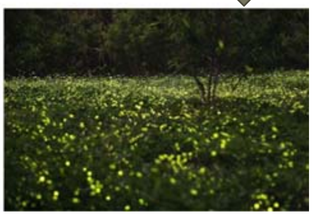
http://www.phys.ncku.edu.tw/~astrolab/mirrors/apod/ap060514.html
http://www.zwbk.org/PictureShow.aspx?pid=20110520111159690_4551.png&title=%u5C04%u7535%u671B%u8FDC%u955C%u9635%u5217&lid=165422

財經報紙 多元整合

相片疊圖 Ex: 拍攝螢火蟲

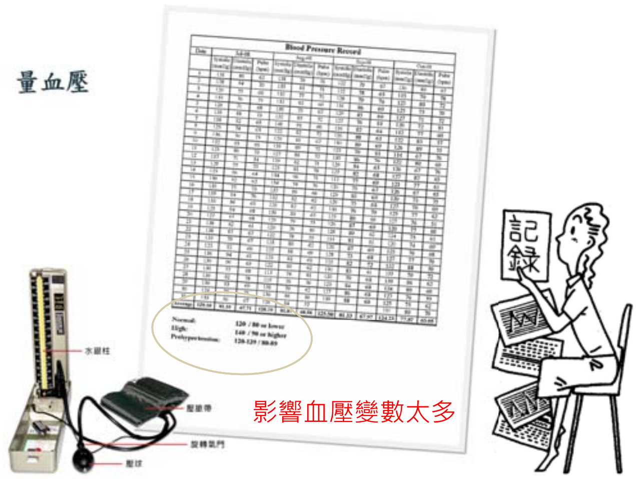


疊圖是拍攝星空常用的技巧，透過多張照片捕捉到的光點，合成為一張內容比較豐富的圖片。



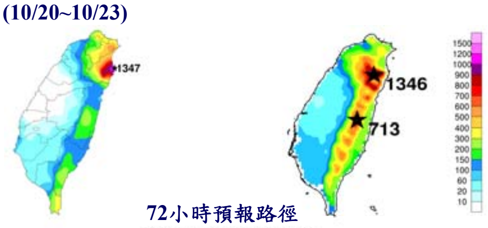
http://blog.lyhdev.com/2009/04/photoshop.ht

量血壓

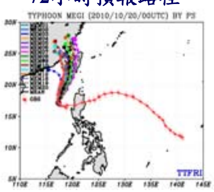


Taiwan Ensemble Rainfall Predictions（梅姬 2010）

Observation (10/20~10/23) **72hr ensemble forecast (mm)**



72小時預報路徑

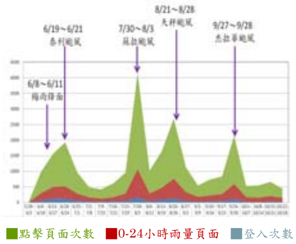


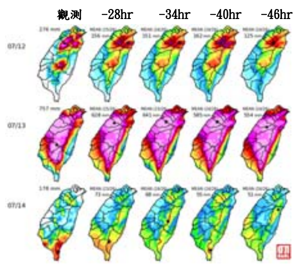
20members

颱風洪水研究中心

定量降雨系集預報實驗

在颱洪中心推動系集降雨預報，協調國內大學、氣象局與防災單位產生26組預報(每日4次)，改善降雨預報，提供65個政府單位防災參考。

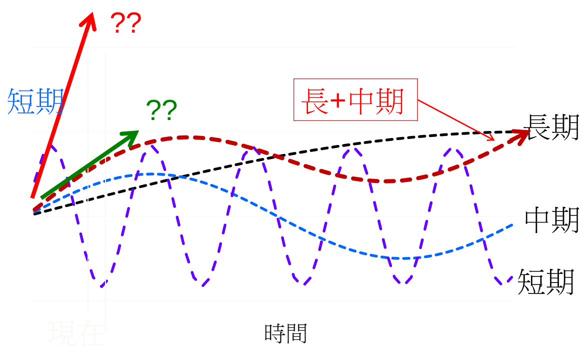




2013年 蘇力颱風

"One economist's trend is another economist's cycle"

不同時間尺度
不同趨勢與循環



張智北教授 提供

總結

•Annual and decadal variations **年、年代際變化、相對海溫重要**

•Typhoon + NE … infall in NE of Taiwan.
（**東北季**

全球暖化？自然變異？年代際變化？
季風變化可能和氣候變遷有關

•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**）

------- 激烈天氣預報對防災重要 ---

•Slow 颱風雨量系集預報 … larger rainfall. （**速慢時長降雨大**）

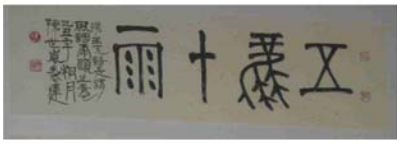
•A positive feedback of rainfall and typhoon translation speed (phase locked ppn)
（**降雨回饋減慢移速**

和全球暖化熱力效應不相同
和全球暖化無直接相關性
地形控制降雨作用，可以掩蓋氣候變遷作用

•Larger … orth), type 2(N) is 3 hour … years. （**地形影響登 … 南快北慢不對稱**）

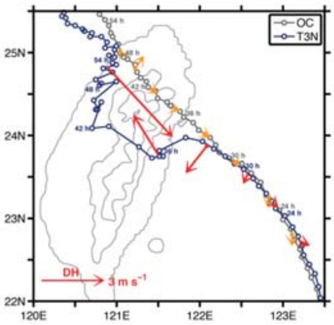
五風十雨 漢王充語是謂風調雨順之意

中央氣象局花蓮站陳世嵐主任書寫

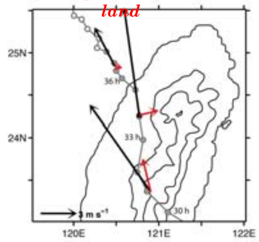


風不鳴條，雨不破塊，五日一風，十日一雨。-- 漢‧王充《論衡‧是應》
夫大塊噫氣，其名為風 。 -- 莊子《齊物》

Northern vs. southern landfall



DH speeds up southern landfall typhoon... while over land



Huge increase of TC rain signifies global warming/climate change effects?

- Pre-landfall and Over-land, the increase is due to longer duration and slight change of tracks. **速慢時長降雨大 降雨回饋減慢移速**
  - Not thermodynamic effect of global warming
  - Link to global climate change less likely
- Terrain effect contributes to a false impression of climate change, yet it strongly controls the rain intensity and masks the climate change. **地形控制降雨作用，可以掩蓋氣候變遷作用。**
- After center exits Taiwan, increase due to stronger monsoon-TC interaction. (but not TC intensity) **西南季風交互作用**
  - Link to global climate change possible:

Global Warming or Natural Variability?自然變異？年代際變化？

“地球溫度每上升一度（水氣多7%），台灣每年前10%的強降雨會增加約140%，而最低20%的小雨則會減少約70%。強降雨增加會增加水災、土石流發生的機率… 氣象局雨量預報需考慮氣候變遷因素。”

“全球暖化 → 海洋增溫 → 颱風變強 → 降雨變多”

雲對流的平均強度受穩定度（輻射冷卻）以及雲微物理效應控制，系統或中尺度降雨，長時間降雨需要特殊降雨機制與大量水氣補充。降雨非僅水氣變多可以推估。
「仍是重要大氣研究課題」

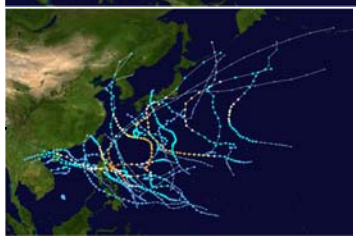
臺灣颱風劇烈降雨發生在最近十年內，和暖化理論所推測的百年變化關係不吻合。

海洋溫度變化和全球暖化不一定相同。
若不界定暖化理論的科學推測，任何討論都沒有意義，因為大氣運動是非線性的，任何兩件事都可以宣稱相關。

年際變化
Annual Variation

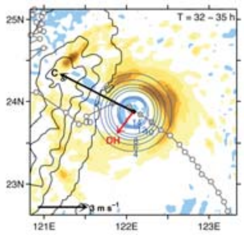
2010

Flood in Thailand
台灣僅一颱風登陸，
930東北季風宜蘭豪雨，
往南海越南方向颱風較多
曼谷大水。



2011

Vertical cross-section of *Q* ...and DH



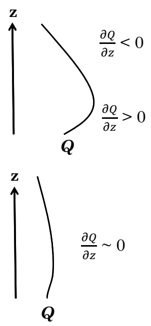
$\int \frac{\partial Q}{\partial z}(\zeta + f)dz < 0$

WN1 Negative

$\int \frac{\partial Q}{\partial z}(\zeta + f)dz \sim 0$

WN1 Positive

schematic



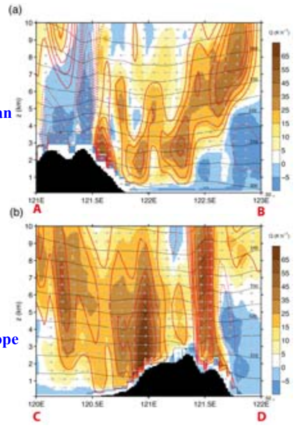
Property of Convection Matters !

$\int \frac{\partial Q}{\partial z}(\zeta + f)dz < 0$

East of Taiwan over ocean

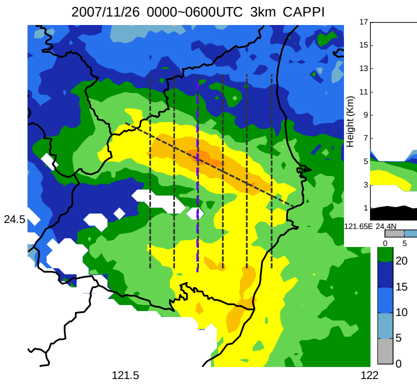
$\int \frac{\partial Q}{\partial z}(\zeta + f)dz > 0$

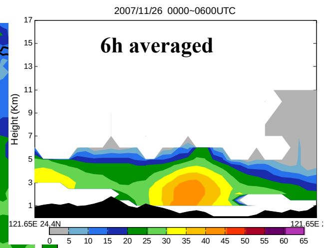
West of Taiwan on the slope



米塔颱風宜蘭超大豪雨

Courtesy of Jou





牛鬥:00-06L
(351mm/6hr)
古魯:07-12L
(228mm/6hr)

Slow "northern landfall" typhoons are with heaviest rainfall amount. (1960-2010)