—演講題目—

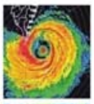
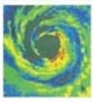
# 颱風、氣候與災害




郭鴻基

教育部國家講座教授
臺大終身職特聘教授
國立臺灣大學 大氣科學系


竹北高中
3/30/2009







## 你快樂嗎？一個簡單的生涯規劃動力系統

$u$：快樂指數
$x$：考試作業量
$y$：玩魔獸的時間

$$\frac{du}{dt} = \frac{\partial u}{\partial x}\frac{dx}{dt} + \frac{\partial u}{\partial y}\frac{dy}{dt}$$

天縱英明的資優生 <0 >0 <0 <0 >0

考試越少越不快樂，
玩魔獸的時間越多越不快樂

$\frac{\partial u}{\partial x}$>0 考試越多越快樂
$\frac{\partial u}{\partial y}$<0 電動越玩越不快樂
→ 人的個性

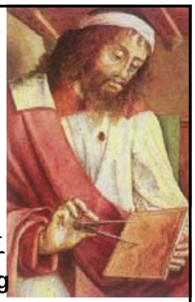
$\frac{dx}{dt}$, $\frac{dy}{dt}$ → 人的境遇

個性+境遇=人生
相形不如論心
論心不如則術
形不勝心
心不勝術 荀子非相



## 讀 算 寫

幾何
代數
微積分
電腦計算繪圖
數學建模/科學計算
Mathematical Modeling
Scientific Computing



| + - | x / |
|---|---|
| 加、減 | 乘、除 |
| 線性 | 非線性 |
| 大題大作 | 小題大作 |



Fovell, 2008 高雄

**This model will be a simplification and an idealization, and consequently a falsification. It is to be hoped that the features retained for discussion are those of greatest importance in the present stage of knowledge.**

**Turning** The Chemical Basis of Morphogenesis



**"Six monkeys, set to strum unintelligently on typewriters for millions of years, would be bound in time to write all the books in the British Museum."** **Huxley**

君子致用在乎經邦，經邦在乎立事，立事在乎師古，師古在乎隨時。必參古今之宜，窮終始之要，始可以度其古，中可以行於今。通典

共49個字，假設中文常用字爲1000字，共有10^147個選擇

地球歷史 10^18 sec
10^10 一百億隻猴子在打字，假設每秒鐘打一萬字 10^4，

10^10*10^18*10^4 = 10^32

10^32/10^147=10^(-115) ~ 0 機率爲零 ，不可能的巧合！

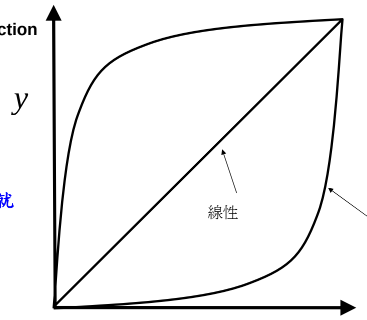
研究學問是苦心孤詣的事業！ 不要人云亦云!

一分耕耘 ， 一分收穫？？

函數 Function

(因果）

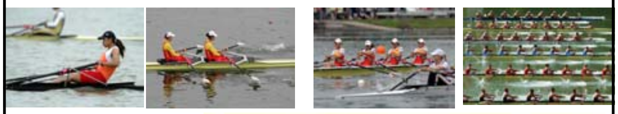
y：成就




$$\frac{dy}{dx} > 0 \Rightarrow \frac{d^2y}{dx^2} = ?$$

x：努力

7



$F \sim \rho v^2 l^2$

$P \sim \rho v^3 l^2$

$G \sim \frac{l^3}{n}$

$l^2 \sim G^{2/3} n^{2/3}$

$P = nA \sim \rho v^3 l^2 \sim \rho v^3 G^{2/3} n^{2/3}$

$v \sim n^{1/9}$

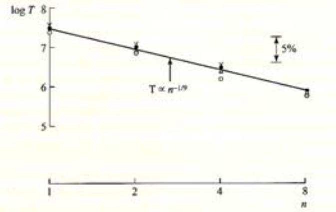



Figure 1.13. The −1/9 power-law dependence of the rowing time $T$ on the number of oarsmen $n$ (solid line). This may be compared with racing times over 2000 m, all at calm or near calm conditions: Δ, 1964 Olympics, Tokyo; ●, 1968 Olympics, Mexico City; ×, 1970 World Rowing Championships, Ontario; ○, 1970 Lucerne International Championships. After McMahon (1971).

Sir Isaac Newton (1642-1727)

## Isaac Newton

## Principia 1687

**Nature and nature's law**
**lay hid in night,**
**God said,**
**Let Newton be,**
**and all was light.　A. Pope**

9

Edmund Halley (1656–1742)

Edmund Halley was a contemporary and friend of Isaac Newton.

He was largely responsible for persuading Newton to publish his *Principia Mathematica*.

Halley and his Comet

Halley's analysis of what is now called Halley's comet is an excellent example of the scientific method in action.

If the astronomers can make accurate 76-year forecasts, why can't the Meteorologists do the same?

Size of the problem
大氣海洋自由度無限 ＋ 熱力學

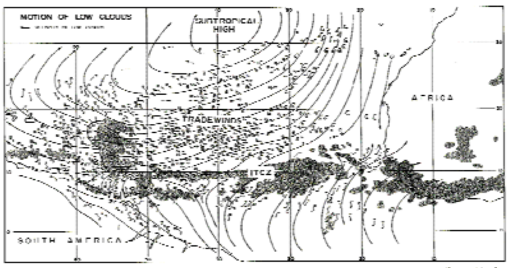
Order versus chaos
大氣海洋的混沌、蝴蝶效應

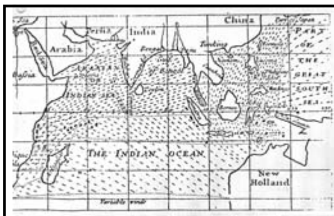
10

Halley 1686

First proposed the atmospheric motion is connected with the distribution of sun heat (follow the sun in the daily scale; thus wind is westward.)


Fujita, 1971




Halley's World Map of Wind Circulations
Fig. 8.1

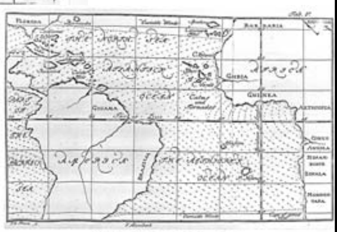
Halley 1686

Sun heat

夸父逐日
東風逐日

D'Alembert 1746

Solar and Lunar force



D'Alembert's Map of the Winds in the Lower Latitudes
Fig. 8.2

## Euler's Equations for Fluid Flow

Leonhard Euler, born on 15 April, 1707 in Basel. Died on 18 September, 1783 in St Petersburg.
Euler formulated the equations for incompressible, inviscid fluid flow:

$$\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V}\cdot\nabla\mathbf{V} + \frac{1}{\rho}\nabla p = \mathbf{g}.$$

$$\nabla\cdot\mathbf{V} = 0$$

流體力學之父

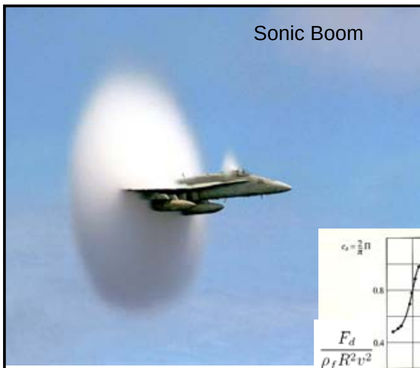
**Partial Differential Equations**
**偏微分方程式 PDE**

非線性

13

---

Sonic Boom



Mach number u/c

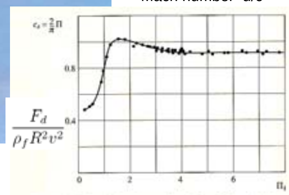



Figure 1.11. The dimensionless drag on a sphere, Π (times 2/π), as a function of the dimensionless governing parameter $\Pi_1 = U/c$, the Mach number (Chernyi 1961). The quantity Π approaches a constant for large values of $\Pi_1$.

Adiabatic Sound; Sonic Barrier

---

**Dead-water near the coast**

**Wave drag problem**

u*u/(g*H)

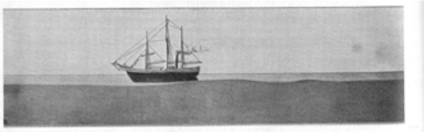
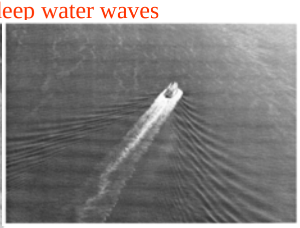


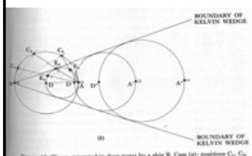
**Fig. 6.2.** (a) Surface "slicks" showing the presence of internal waves in the wake of a ship in Bute Inlet, British Columbia. The vessel was traveling at 0.5 m $s^{-1}$ in a surface layer of almost fresh water only slightly deeper than its 3.4 m draft. The internal waves caused horizontal motion at the surface that affects the ripple pattern and so renders the internal wave pattern visible at the surface during calm conditions. [Photo courtesy of Defence Research Establishment Pacific, Victoria, British Columbia.] (b) A laboratory experiment [from Ekman (1904)], showing internal waves being generated by a model ship. The tank is filled with two fluids of different density, the heavier one being dyed to make the interface clearly visible. The model ship (the superstructure of the "Fram" has been drawn in subsequently) is towed from right to left, causing a wake of waves on the interface.

---

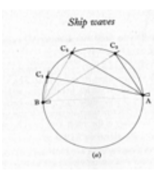
Kelvin wedge　　deep water waves



[*Courtesy of Aerofilms Ltd.*]




$$2*\sin^{-1}\left(\frac{1}{3}\right) = 2*19.5^{\circ}$$




---

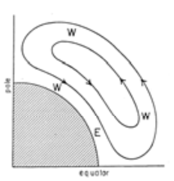



*Fig. 2.* A schematic view of a meridional cross-section of the general circulation as visualized by Hadley (1735). Streamlines indicate the meridional and vertical flow, while letters E and W indicate regions of easterly and westerly flow.

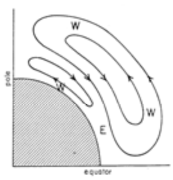



*Fig. 3.* The same as Fig. 2, but for the general circulation as visualized by Thomson (1857) and Ferrel (1859).

**Hadley** (1685-1758)

Distribution of **sun** heating (north and south; seasonal scale)

Earth **rotation** (conservation of angular momentum)

Thomson (1857)
**Ferrel** (1859)

**Centrifugal force**

**Coriolis** **1835**

**D'Alembert** **1746**

Math. Model for Atmospheric Motion in aqua-planet
(Won the 1746 Berlin Academy's Award; Euler's endorsement)

**Solar and Lunar Force**

**Fourier** **1768-1830**

Why the earth not heating up when receive sun energy continuously?

**Heat emission or diffusion (by IR)**

His calculations showed a very cold surface (No green house effect)

**Arrhenius** **1896**

**$CO_2$ green house effect**, but were dismissed by scientists [WHY??]

17

---

**Ideal Gas Law** **Equation of State 理想氣體方程**

- **1662, Boyle law,** PV = c when T = c.
- **1787, Charles law,** V/T = c when P = c.
- **1803, Gay-Lussac law,** P/T = c when V = c.
- **1811, Avagardro, 1 mole gas is 22.4 l in volume.**

**Universal Gas Constant**
**R* = 8314.3 J /(deg.・kmol)**

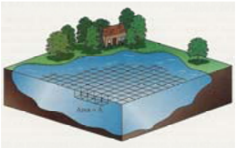
P = f(V, T)
V = h(P, T)
溫度可以改變壓力或體積，熱可以做功

**PV = n R* T**
**PV = m/M R* T　P = m/V R*/M T**
**P = ρ R T, R = R*/M**
**$R_d$ = 287 J/deg.kg　(R*/$M_d$)**
**$R_v$ = 461 J/deg.kg　(R*/$M_v$)**

18

## Estimate Avogadro's Number

Benjamin Franklin ( 1773 )



Oil spreads on water
⟶ molecular size
⟶ Avogadro's number

(1) Molecular size

$$l = \frac{V}{A} = \frac{4.9\ \text{cm}^3}{2.0 \times 10^7\ \text{cm}^2} = 2.4 \times 10^{-7}\ \text{cm}$$

(2) Number of molecules

$$N = \frac{A}{l^2} = \frac{2.0 \times 10^7\ \text{cm}^2}{(2.4 \times 10^{-7}\ \text{cm})^2} = 3.5 \times 10^{20}\ \text{molecules}$$

(3) Mass of the oil

$$m = V \times D = 4.9\ \text{cm}^3 \times 0.95 \frac{\text{g}}{\text{cm}^3} = 4.7\ \text{g}$$

(4) Number of moles of oil

$$\text{Moles of oil} = \frac{4.7\ \text{g}}{200\ \text{g/mol}} = 0.024\ \text{mol}$$

(5) Avogadro's number

$$\text{Avogadro's number} = \frac{3.5 \times 10^{20}\ \text{molecules}}{0.024\ \text{mol}} = 1.5 \times 10^{22}$$

Now we know: $N_A = 6.022142 \times 10^{23}$ /mol

---

Development of Thermodynamics 熱力學
19 century

第一定律 能量作功，能量守恆
First law: Energy is what makes it go and energy is conserved.
△Q = △U + WORK 能量=內能+功

Second law: Entropy tells it where to go!
第二定律 時間之矢，自然單向

**Joule, Rudolf Clausius, Lord Kelvin and others**

宏觀 微觀
**Macro --- Micro**
**Classical and Statistical Thermodynamics**
統計熱力學

**Ludwig Boltzmann, 1844-1906, whose work led to an understanding of the macroscopic world on the basis of molecular dynamics.**

S = k Log W

雲微物理
**Precipitation**

**Enthalpy**
**Entropy**
**Gibbs Free energy**


---

## Planck, Unwilling Revolutionary: the idea of quantization

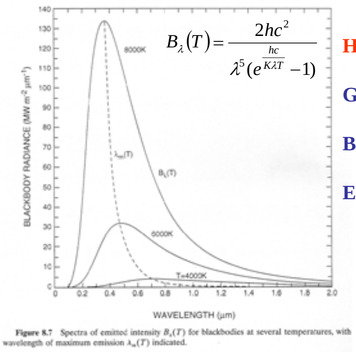



Figure 8.7 Spectra of emitted intensity $B_\lambda(T)$ for blackbodies at several temperatures, with wavelength of maximum emission $\lambda_m(T)$ indicated.

黑體輻射公式

**1900**

**Hall of Fame in Science**

**Gravitational Law**

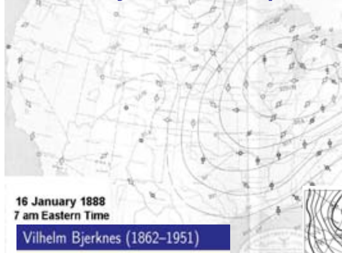
**Blackbody Radiation**

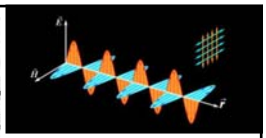
**E= MC^2**

21

---

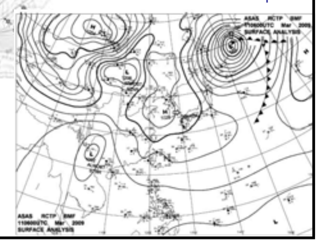
## 19 century weather map



Maxwell 電磁波

Modern weather map



---

The Ultimate Problem in Meteorology Bjerknes 1911
氣象的終極問題

I The Present state of the atmosphere must be characterized as accurately as possible. 正確的觀測大氣現狀
[多重時空尺度]

II The intrinsic laws, according to which the subsequent states develop out of the preceding ones, must be known.
正確的大氣運作規律

Numerical Weather Prediction 數值天氣預報
[第一部電腦ENIAC, EBV model, 1950]
The Observation component 觀測
The diagnostic or analysis component 診斷分析
The prognostic component 預報

23

---

科氏力(18 19)

**Momentum Conservation (18)**

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\nabla^2 u$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + fu = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \nu\nabla^2 v$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g + \nu\nabla^2 w$$

**Mass conservation (18)**

$$\frac{\partial \rho}{\partial t} + \frac{\partial u\rho}{\partial x} + \frac{\partial v\rho}{\partial y} + \frac{\partial w\rho}{\partial z} = 0$$

**Energy conservation (19)**

$$\frac{\partial \theta}{\partial t} + u\frac{\partial \theta}{\partial x} + v\frac{\partial \theta}{\partial y} + w\frac{\partial \theta}{\partial z} = Q$$

**Equation of State(17,18,19)**

$$p = \rho R_a T, \quad \theta = T\left(\frac{p_0}{p}\right)^{\frac{R_a}{C_p}}$$

(19)

**Radiation**
大氣輻射
**(19,20)**
**Moisture**
**Latent heat**

雲物理
**(19,20)**

問蒼茫大氣，誰主浮沈？
質量、動量、能量與大氣狀態方程式

24

# Lewis Fry Richardson, 1881–1953.


During WWI, Richardson computed by hand the pressure change at a single point.

It took him two years !

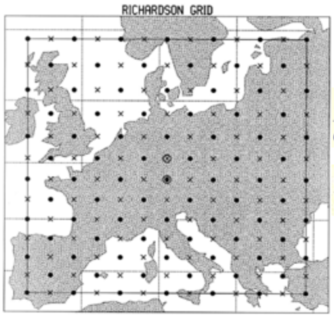
His 'forecast' was a catastrophic failure:

$\Delta p = 145$ hPa in 6 hours

His method was unimpeachable.

So, *what went wrong?*

*Peter Lynch*




$$\frac{df}{dx} \rightarrow \frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x}$$

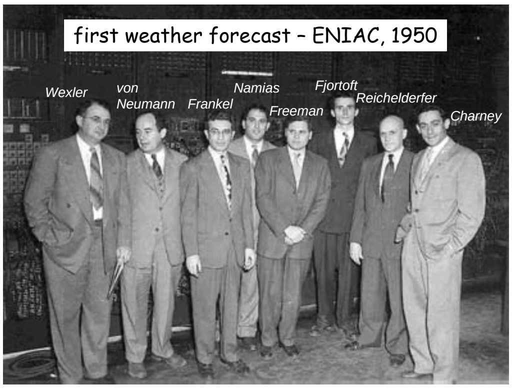
$$\frac{dQ}{dt} \rightarrow \frac{Q^{n+1} - Q^{n-1}}{2\Delta t} = F^n$$

13x13=169個ODE

169 自由度

26

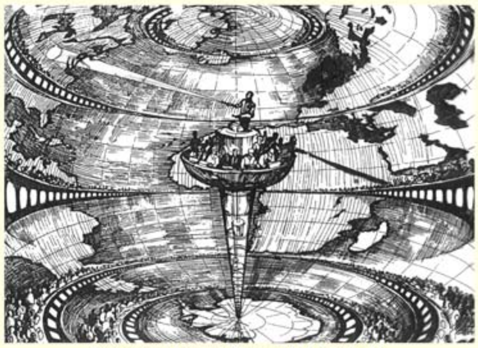
## first weather forecast – ENIAC, 1950




*In front of the Eniac, Aberdeen Proving Ground, April 4, 1950, on the occasion of the first numerical weather computations carried out with the aid of a high-speed computer.*

27

## Richardson's Dream



Richardson's Forecast Factory (A. Lannerback).
Dagens Nyheter, Stockholm. Reproduced from L. Bengtsson, ECMWF, 1984

64,000 Computers: The first Massively Parallel Processor

## The ENIAC — Electronic Numerical Integrator and Computer

**18000 vacuum tubes**
**70000 resistors**
**10000 capacitor**
**6000 switches**

**140 K Watts power**

**No high-level language**
**Assembly language**

**500 Flops**
**Function Table 0.001 s**

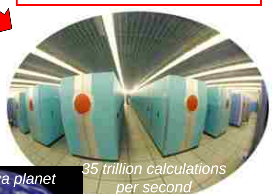
**3,700,000,000** times slower than current day large computer

第一部電腦　氣象預報

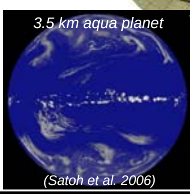
29

*ENIAC – late 40s*

*Earth Simulator -- 2002*



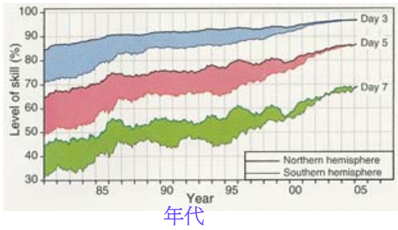

*NASDA, JAERI, JAMSTEC*




30

南北半球 對於3，5，7天之預報能力隨時間的進展

預報能力指標




年代

南北差異日漸減少主要是由於近年來衛星觀測以及資料同化技術日漸成熟

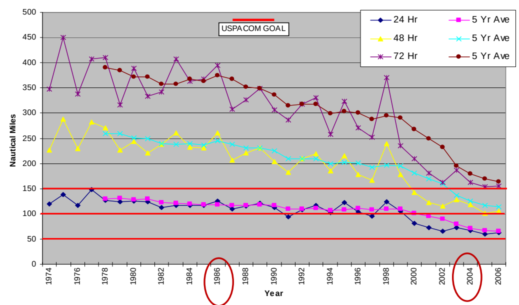
**7天預報一年進步約1.5%，3天預報一年進步0.3%**

31

West Pac Track Errors

Edward Fukada
JTWC

Error cut in half since 1990

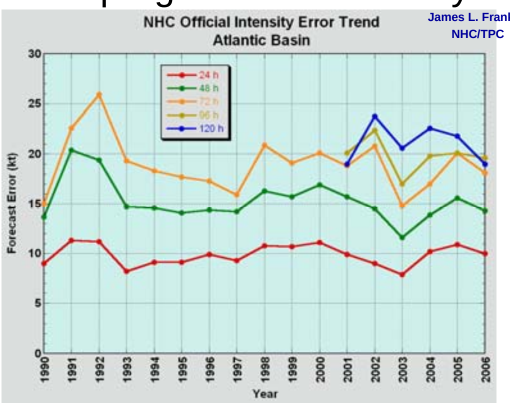



美國飛機停止觀測

台灣飛機觀測

32

# No progress with intensity




James L. Franklin
NHC/TPC

33

## 颱風潛熱與其它能量的比較

賀伯颱風的全台灣平均總雨量

為400*mm*

$400\ mm = 0.4\ m$

$0.4\ m * 1000\ kg\ m^{-3} * 2.5\times10^{6}\ J\ kg^{-1}$

$= 10^{9}\ J\ m^{2}$

$10^{9}\ J\ m^{2} * 3.5\times10^{10}\ m^{2}$

$= 3.5\times10^{19}\ J \sim 10^{20} J$

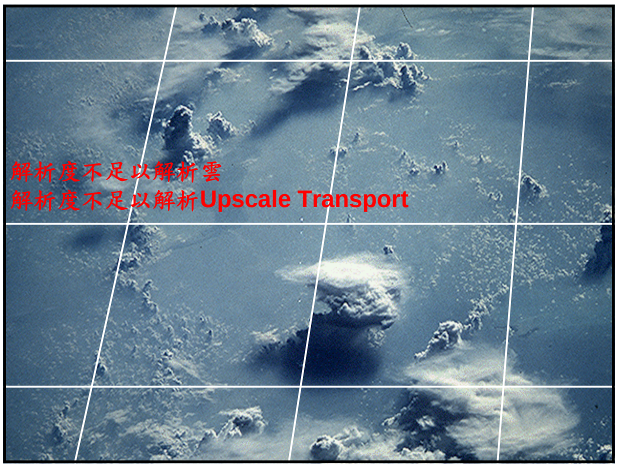
$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n$$

$1.68 * m * 10^{13} J/mol$

$\Rightarrow 1.46\times10^{6}\ kg\ U^{235}$ ( $6*10^{6}$ mol )

| 能量估計值 | | 備註 |
|---|---|---|
| 賀伯颱風降雨總潛熱能量 | $10^{20}$ J | 可使台灣整層大氣增溫100度 |
| 台灣一年用電量 | $5*10^{17}$ J | 需數百年用電量才相當 |
| 全世界核子彈爆炸釋放能量 | $2*10^{19}$ ~$2*10^{20}$ J | 與賀伯颱風同等級 |
| 核戰後燃燒釋放能量 | $2*10^{20}$ J | 與賀伯颱風同等級 |
| 地球一天接受的太陽能量 | $1.5*10^{22}$ J | 數百個賀伯颱風 |
| Tunguska隕石撞地球 （西元1908年，西伯利亞） | $10^{16}$ J | 賀伯颱風的萬分之一 |
| 火流星撞地球（恐龍滅絕？） | $4*10^{23}$ J | 數千個賀伯颱風 |

34



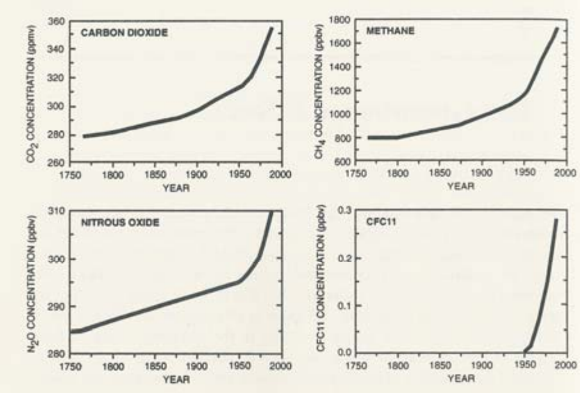


水氣是最重要溫室氣體，輻射效應是二氧化碳1000倍強！

煤炭火力發電是問題所在。

36

二次大戰後的快速增加　　經濟發展＋沒有世界大戰



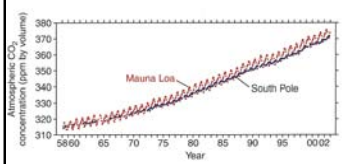

凝結尾　　人為

Fig. 10.43 Condensation trails. [Photograph courtesy of Art Rangno.]

During the 3 days after the 9/11 /2001, statistical significant increase of 1.1C in the average diurnal temperature range for ground station across US.

38

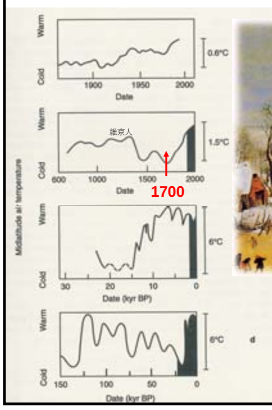
**Keeling Curve (1958-　)**




*Charles Keeling (left) at the dedication of the Keeling Building at the Mauna Loa Observatory, Hawaii (1997)*

39

氣候變遷　　**Warming trend begins 1700A.D.**



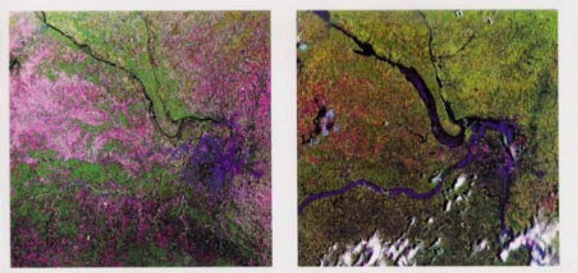

Bruegel, Pieter, the Younger
< Winter Landscape (1601) >

自然？？　人爲？？

40

風雨之不時，是無世而不常有之。　荀子天論

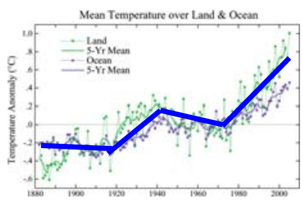
1988　年際變化 季節預報　1993



*Heavy rains in the summer of 1993 produced floods along most of the Mississippi River in the central United States, as shown in these Earth satellite photographs of St. Louis, Missouri on July 4, 1988 (left) and July 18, 1993 (right). Extreme climatic events may be increasing in frequency as a consequence of added radiative absorbing gases in the atmosphere.*

41

SPECIAL REPORT
Business & Media Institute
MAY 17, 2006
FIRE AND ICE
Journalists have warned of climate change for 100 years, but can't decide weather we face an ice age or warming

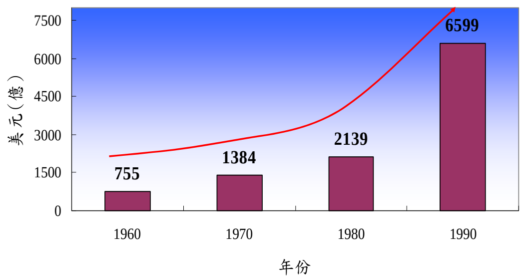



A New York Times-line

| "MacMillan Reports Signs of New Ice Age" | "America in Longest Warm Spell Since 1776; Temperature Line Records a 25-Year Rise" | "Scientists Ponder Why World's Climate is Changing; A Major Cooling Widely Considered to Be Inevitable" | "Past Hot Times Hold Few Reasons to Relax About New Warming" |
|---|---|---|---|
| Sept. 18, 1924 | March 27, 1933 | May 21, 1975 | Dec. 27, 2005 |
| - | + | - | + |

42

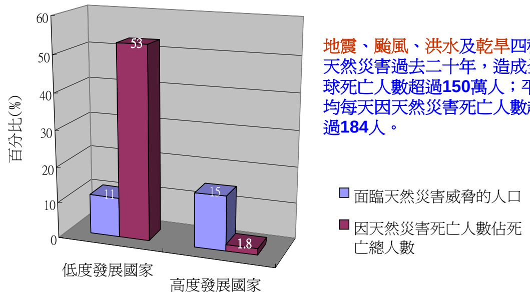
## 全球天然災害造成經濟損失




資料來源：聯合國UNDP報告(2004)



## 災害防救已成爲全球重要議題




地震、颱風、洪水及乾旱四種天然災害過去二十年，造成全球死亡人數超過150萬人；平均每天因天然災害死亡人數超過184人。

資料來源：聯合國UNDP報告(2004)

落實推動災害防救工作

→ 人民因天然災害死亡的機率可減低40倍！



J A N U A R Y 3 1


1 9 7 7



# Science Digest

**February, 1973**

Reports that the world's ***climatologists are agreed*** that "we must prepare for the next ice age."


Time magazine's June 24, 1974, story showed how Arctic snow and ice had grown from 1968 to 1974.

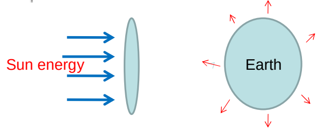
A P R I L 3


2 0 0 6



$$C\frac{dT}{dt} = S\downarrow - IR\uparrow$$

比熱 specific heat



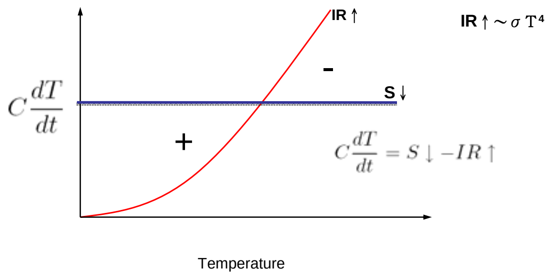

$S\downarrow = \pi a^2\, s(1-\alpha)$　　$IR\uparrow = 4\pi a^2\, \epsilon\sigma T^4$

反照率 albedo

比熱　　海水 深層海水

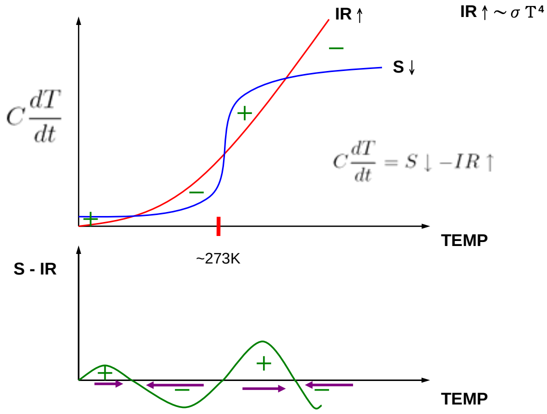
反照率　　冰雪　　雲（IPCC沒討論的因素，氣象最大的挑戰）

太陽常數　天文因素　太陽物理



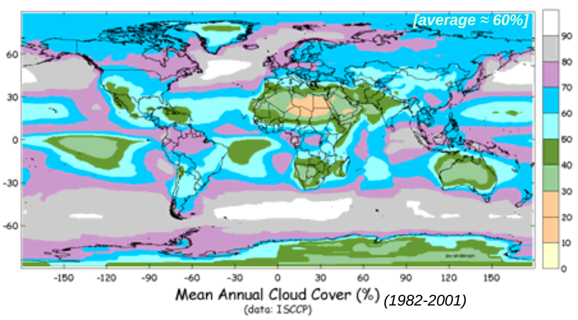

Don't Worry! Be Happy!

49




50

2 stable multiple equilibria




(1982-2001)

- *The climate system is sensitive to cloud cover and cloud type*
- *There is conflicting evidence on changes in global cloud cover over past 2-3 decades; reported trends vary by cloud type*
- *Deep convection impacts cirrus cloud coverage*

Evidence

Volcano Eruption

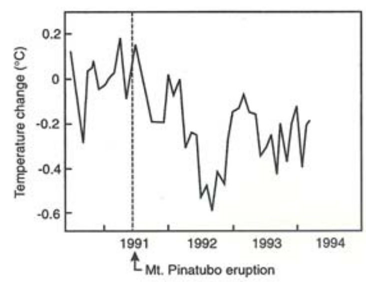



**Fig. 8-6** Observed change of the Earth's global mean surface temperature following the Mount Pinatubo eruption (June 1991). Adapted from Intergovernmental Panel on Climate Change. *Climate Change 1994*. New York: Cambridge University Press, 1995.

A year without summer

Memory effect

Jacob (1999)

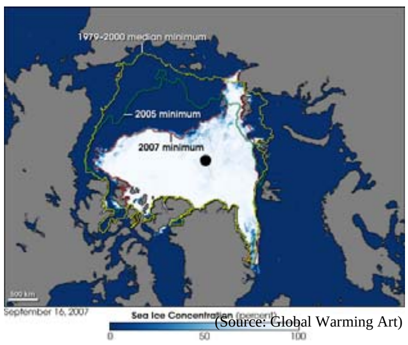
52

德國的小北極熊 (紐倫堡)

我見猶憐！

# 北極海冰新低紀錄

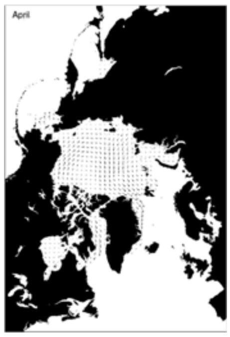
北極熊、企鵝海象在125000年前時已經存活
（比目前氣候2度溫暖，海水高6公尺）。




(Source: Global Warming Art)

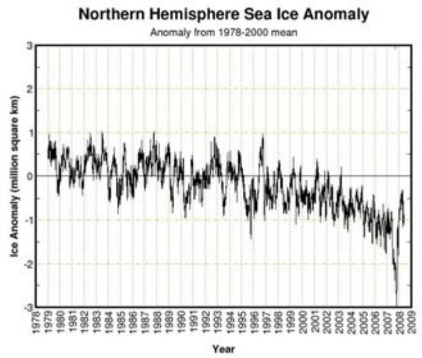
# 異常海冰融解原因

- 長期海冰薄化提供快速融冰基礎
- 2007年夏季持續高壓籠罩，太陽輻射與高壓環流吹散海冰為近因(可能是AO現象)
- 融冰程度遠超過模式預測




54

# 北半球海冰現況




55

# 2007北極海冰極小值的啟示

「2008九月前北極冰恐消失」2008.6.28中時

"chances are 50(%) and 50(%)"

- 2007極小值遠低於所有模式預測
  - 再次顯示我們對氣候(天氣)系統理解的不足
  - 也可能再回復
  - 未來持續縮小趨勢機會很高
- 北極海冰覆蓋面積大，對全球氣候應有影響
  - 短期變化應該與全球暖化無直接關連
  - 所謂氣候自然變異幅度絕不可輕忽
  - 長期趨勢仍是值得關注的全球暖化指標
- 北極海冰變化尚無影響全球深海循環的證據

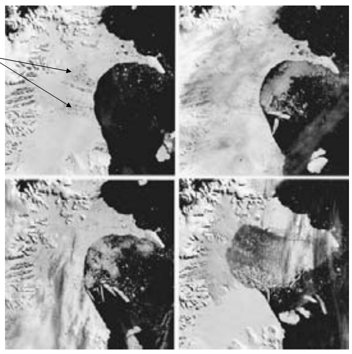
56

# 2002南極冰棚大崩塌

2002.01.31

出現裂縫

冰河運動擠壓本來就容易形成裂縫，夏季表面融雪流入裂縫，雪水復冰後體積膨脹，或水壓本身使裂縫加深而延伸，使冰棚結構脆弱化，開始崩塌後引發連鎖反應，終致大面積崩塌。

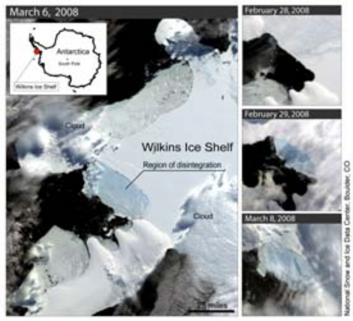


冰棚碎裂後，海水入侵間隙，大的接觸面積與溫差，加速浮冰再碎裂與融化速率。

2002.03.05

57

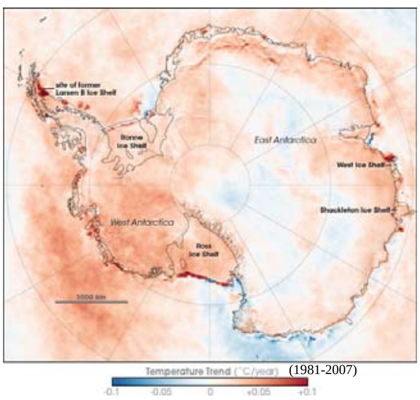
# 2008.2.28威爾金冰棚大崩塌




威爾金冰棚總面積14,500平方公里；可能崩塌冰棚中面積最大者；2008崩塌面積415平方公里；1998.3崩塌面積1098平方公里。

近年大崩塌冰棚：
Prince Gustav Channel,
(1995, 650平方公里)
Larsen Inlet,
Larsen B,
(2002.1.31, 3250平方公里)
Wordie,
Muller,
Jones shelves.

58



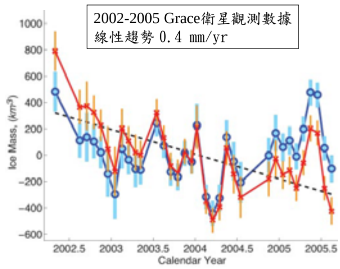

(1981-2007)

59

# 南極冰原質量平衡現況與趨勢

- 有關南極冰原質量平衡機制的理解仍相當有限
- 南極洲面積大，傳統冰原觀測數據相當有限，相關研究結論亦頗不一制，IPCC定為「高度不確定」
- 衛星觀測數據時間長度過短，尚不宜過度引申

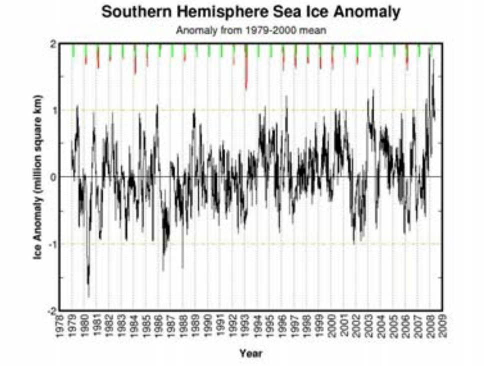
2002-2005 Grace衛星觀測數據
線性趨勢 0.4 mm/yr




南極冰原質量平衡觀測

60

## 南半球海冰現況對照



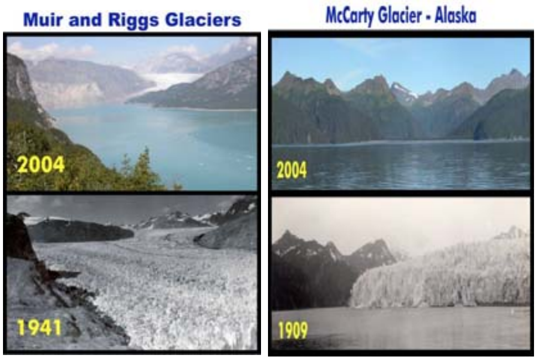

61

## 高山冰河退縮問題

- 高山冰河退縮常被作為全球暖化指標
  - 「不願面對的真相」令人震撼的「暖化指標」之一
- 冰河是研究古氣候的重要資訊來源
  - 冰河中永凍的古生物與鑽探分析的冰核保留豐富資訊
- 高山冰河同時是自然生態與人類活動的重要淡水來源
  - 冰河是天然水庫— 主要江、河常源自高山冰河
  - 「瑞雪兆豐年」— 冰河釋出的水可能是部分地區唯一或主要水源

62

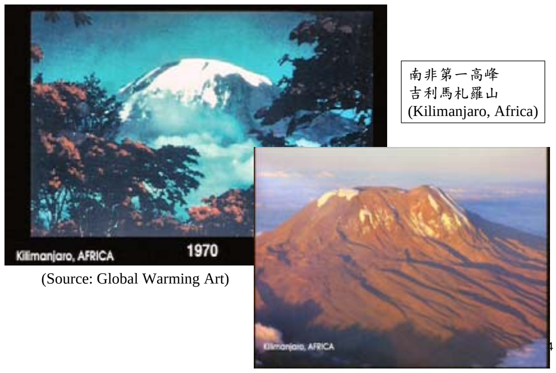
## 冰河退縮影像




## 冰河退縮影像

溫度沒有升高
降雪減少

南非第一高峰
吉利馬札羅山
(Kilimanjaro, Africa)




(Source: Global Warming Art)

## 全球海平面上升議題


- 符合直覺式的全球暖化聯想
  - 一般民眾最能體會、最關心的議題
  - 「大洪水」的聯想 （諾雅方舟？）
- 全球暖化論述最嚴重的潛在威脅
  - 人類主要的居住、生產、經濟活動都在沿海的低海跋區域
    - 幾乎不分國家或地區的開發程度都可能受嚴重衝擊
  - 沿岸區域是地球生態系統最豐富的區域之一
    - 近岸地形對海平面變化敏感，過於快速的海岸線變化恐造成生態浩劫
- 陸地海跋高度係以平均海平面為基準

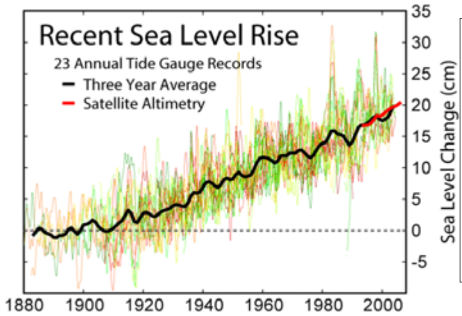
65

## 平均海平面估算的困難

- 海平面變化含有各種時間尺度
  - 幾乎是連續的頻譜，量測與頻譜分離都不容易
- 量測點不足、時間長度有限
- 早期量測係以陸地為基準的相對值
  - 地殼變動因素複雜、各地情況也不一致
- 海平面升降具有明顯區域特性
  - 受區域氣候、洋流、海水溫度影響

66

## 近百年海平面變化概況

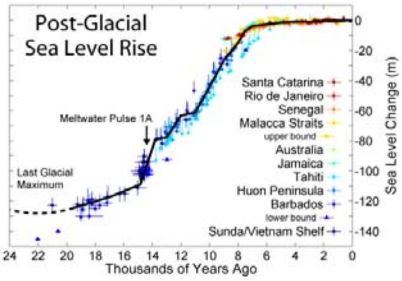



此圖依據23長期潮位站資料繪製，僅能作為參考；
1900年以來平均約18公分/百年；
近代衛星觀測試(紅)上升率略高，約3.1公分/百年；
IPCC整理之19世紀數據為-8-22公分/百年；
海水熱膨脹貢獻約3-8公分/百年。

(Source: Global Warming Art)

67

## 大冰期海平面變化




18,000年前至今，平均海平面約上升130公尺；
主要海平面上升約終止於6,000年前；
3,000年前至20世紀初，海平面幾無變化；
上個間冰期最高海平面可能比現今高4-6公尺。

(Source: Global Warming Art)

68

## 還有多少陸冰留存？

- 東南極洲(高原) 61.1 m
- 格陵蘭 7.2 m
- 西南極洲(部分低於海平面) 5-6 m
- 其它 0.5 m

- 海水熱膨脹係數約 $2.1\times10^{-4}\ ^{\circ}K^{-1}$
  – 500m深海水增溫1度，海面將升高10 cm

69

## 不願面對的真相

- 獲得2006奧斯卡最佳紀錄片和最佳原創音樂兩座獎項
- 促成高爾和IPCC共同獲得2007諾貝爾和平獎殊榮
- 英國倫敦高等法院的判例
  – 由Justice Michael Burton所裁定
  – 高爾在片中闡述的氣候變遷原因與可能衝擊大致正確，因此可以繼續在學校播放
  – 但是，此影片犯了**九個**不符合主流科學共識的「錯誤」
  – 放映時教師必須針對偏見與「錯誤」提供平衡觀點的說明


70

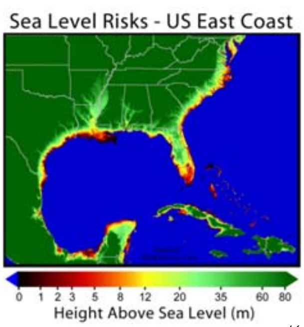
## 法官提出的9點「錯誤」

1. Sea level rise of up to 20 feet (7 metres) will be caused by melting of either West Antarctica or Greenland in the near future
2. Low lying inhabited Pacific atolls are being inundated because of anthropogenic global warming
3. Shutting down of the "Ocean Conveyor“
4. Direct coincidence between rise in $CO_2$ in the atmosphere and in temperature, by reference to two graphs
5. The snows of Kilimanjaro
6. Lake Chad etc
7. Hurricane Katrina
8. Death of polar bears
9. Coral reefs

71

## 1. 精彩的系列淹水動畫

- 是電影中使用最多畫面的單一議題
  – 被批評為典型的災難電影手法，過於誇大、無依據
- 電影中說明格陵蘭或西南極洲冰原可能融化，然後就可能有這些現象
  – 沒有明說時間，但**給人「很快就可能發生」**的印象
- 支持者認為
  – 依據IPCC的溫度推估，本世紀結束前全球溫度幾乎一定超越上個間冰期的最高溫，當時的海平面就比現今高約4-6公尺
  – 基本上只是時間尺度有點混淆的問題，不算刻意誇大
  – 支持者其實也大都認為本世紀內不可能發生這種水淹狀況




72

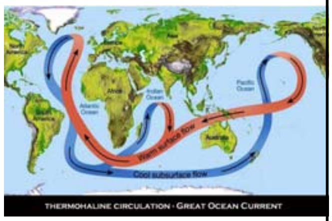
## 太平洋島國必須逃難

- 高爾以土哇魯為例，說明這個島國國民因此須要逃難到紐西蘭
  - 被批評說「根本沒這回事」
- 電影中是接在2002南極冰棚大崩塌之後，說明陸冰也可能崩塌而造成非預期的海平面上升，像土哇魯這樣的地方就因此需要逃難到紐西蘭
- 事實是土哇魯的確因為「地層下陷」與風暴造成的「海岸侵蝕」而使生存環境越來越惡劣
  - 和全球暖化沒有直接相關
  - 電影之後，土哇魯剛好巧合的和紐西蘭討論租地的事
  - 支持者認為只是「示意」，用個方便的例子，可能是錯誤選擇，但無傷大雅

聖嬰年西太平洋海水高度會降～50 cm

73

## 3. 深海循環中斷




- 被批評花太多時間說明一個很不可發生的情況，會發生的話也要數百年至數千年之後
- 電影中直接點出了「新仙女木事件」，目的是在解釋一個可能引發氣候劇烈變化的物理機制，有點像是在解釋電影「明天過後」的邏輯，但比較科學多了
- 事實上NOAA和IPCC都有正式聲明，這個氣候變異機制「很不可能」在未來百年內發生
  - 支持者認為這是個很重要的氣候變異機制，值得介紹
  - 這個機制還有許多未知的細節，學理上其實無法完全排除在未來發生的可能，只是時間尺度的確應在百年以上
- 這是我最喜歡的氣候變異理論之一，支持！

74



Bryden and Longworth *Nature* 2005

| | |
|---|---|
| 1957 | $22.9 \pm 6\ SV$ |
| 2004 | $14.8 \pm 6\ SV$ |
| Net | $8.1 \pm 6\ SV$ |

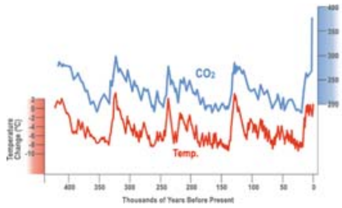
$$1\ SV = 10^6 m^3 s^{-1}$$

correct result. It is a mystery how such an error was missed by Levi and by the editors and reviewers of the original paper. The observed change of 8.1 Sv is well within the uncertainty of the measurement. The correct conclusion from

$8.1 \pm 12\ SV$

## 4. 溫度隨$CO_2$濃度「高升」

- 被批評誤導$CO_2$濃度和溫度變化的因果關係
  - 這是真正理論氣候學者討論最多的主題
- 電影中先說明兩者65萬年來的明顯相關性，然後以預期的$CO_2$濃度直接預估(暗示)未來可能的溫度




- 古氣候變異中，可能$CO_2$濃度是反映溫度變化，然後提供一個正回饋機制，冰核分析上的確有溫度領先$CO_2$濃度的相位差存在
  - 反全球暖化的人，以溫度領先$CO_2$濃度的現象來反證全球暖化「 $CO_2$濃度引發暖化」的論點不成立，這個邏輯本身不正確
  - 由溫室效應的觀點來看，溫度因$CO_2$濃度而變的邏輯是正確的
  - 但是人為溫室氣體排放作用並沒有發生在遠古時代，電影中直接拿來對比應該不是很恰當

76

## 5. 吉利馬札羅冰河

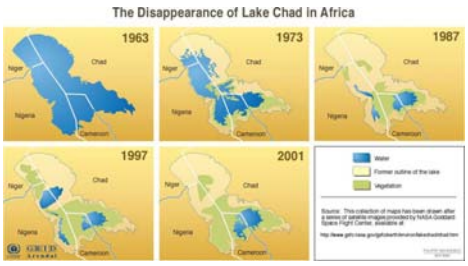
Local change or Global change??

- 媒體特別鍾情吉利馬札羅山，法官認為不應妄下結論，該冰河消失原因與全球暖化的關係未明
- 電影中這是一系列冰河退縮對比中的一景
- 吉利馬札羅山冰河退縮的真正原因的確尚無定論
  - 冰河退縮是個全球性普遍的趨勢，但是也有冰河持續發展中，而每條冰河變化的原因也都不盡相同，此例用來說明冰河退縮現象還可以，用來說明全球暖化的結果就太勉強了
  - 現今殘存的吉利馬札羅山冰河至少已存在12,000年以上，這個變化的原因應該個值得關心的問題

77

一個「拜錯菩薩燒錯香」的例子？

## 6. 乾涸中的查德湖




- 被批評不應當成「暖化後果」的例證，實情應該是**人口增加、過度取用灌溉水源**、及區域氣候變遷影響
- 電影中是用來說明暖化的結果，「有些地方會發生洪水、有些地方會產生乾旱」
- 是水資源使用的問題，不過部分全球暖化模擬的確預測該區降水減少

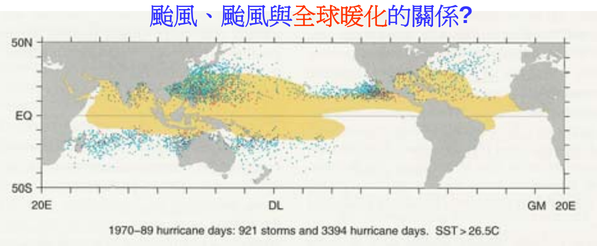
78

# 7. 卡翠那颶風

- 被批評不應把卡翠那颶風在紐澳良造成的災難歸因於全球暖化，這已是科學界的共識
- 電影中高爾未明說，但邏輯延續上的確會被解讀為「這就是暖化的後果之一」
- **任何獨立天氣事件都不應直接被歸因於全球暖化，IPCC也接受這個觀點**

79

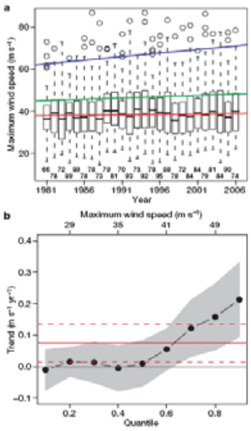
## 颱風、颶風與全球暖化的關係?




| | North Atlantic | Eastern N Pacific | Western N Pacific | North Indian | Southwest Indian < 100E | Australia / SE Indian | Australia / SW Pacific | Totals |
|---|---|---|---|---|---|---|---|---|
| Average | 9.7 | 16.5 | 25.7 | 5.4 | 10.4 | 6.9 | 9.0 | 83.7 |
| Standard Deviation | 3.1 | 4.1 | 4.1 | 2.1 | 2.6 | 2.4 | 3.1 | 7.8 |
| Global total (%) | 11.6 | 19.8 | 30.7 | 6.5 | 12.4 | 8.2 | 10.8 | 100.0 |

80

81




## Recent TC Intensity Trends

There is some statistical evidence that the strongest hurricanes are getting stronger. This signal is most pronounced in the Atlantic. However, the satellite-based data for the global analysis are only available for 1981-2006.

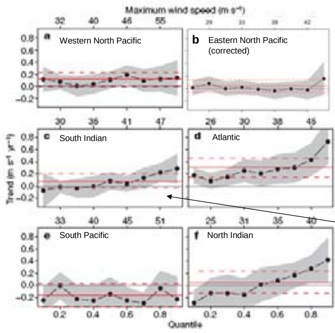
Quantile regression computes linear trends for particular parts of the distribution. The largest increases of intensity are found in the upper quantiles (upper extremes) of the distribution.

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

81

82

## Regional Structure of Tropical Cyclone Intensity Trends




There statistical evidence that the strongest hurricanes are getting stronger is most convincing for the Atlantic (1981-2006).

The North and South Indian Ocean data also suggest increased intensity, but data homogeneity concerns are still being debated for those regions.

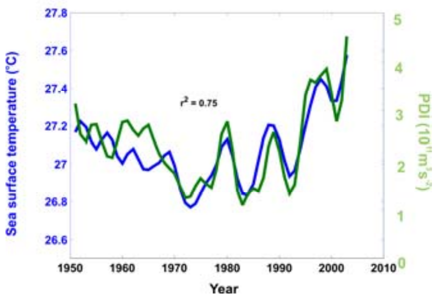
The intensity change signal is quite weak for the Pacific basin.

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

82

83

There is some recent evidence that overall Atlantic hurricane activity may have increased since in the 1950s and 60s in association with increasing sea surface temperatures…



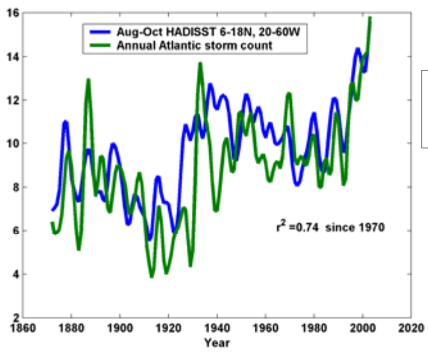

PDI is proportional to the time integral of the cube of the surface wind speeds accumulated across all storms over their entire life cycles.

Source: Kerry Emanuel, J. Climate (2007).

83

84

## The frequency of recorded storms (low-pass filtered) in the Atlantic basin is well-correlated with tropical Atlantic SSTs

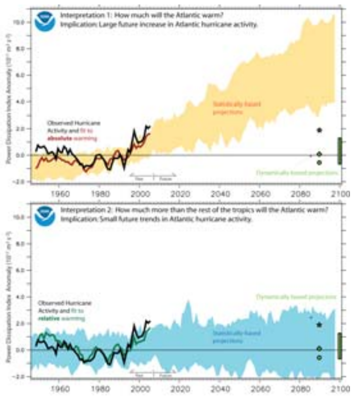



But is the storm record reliable enough for this?

Source: Emanuel (2006); Mann and Emanuel (2006) EOS. See also Holland and Webster (2007) *Phil. Trans. R. Soc. A*

84

Two future projections of Atlantic tropical cyclone power dissipation




Projection 1:
Tropical Atlantic SST

Some worrisome time series…

Some alternative perspectives…

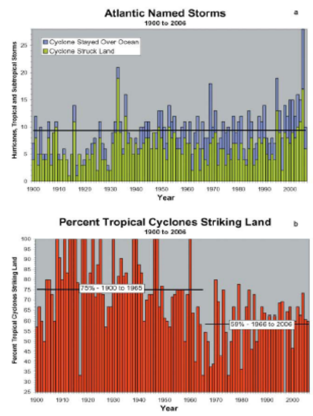
Projection 2:
Tropical Atlantic SST Relative to Tropical Mean SST

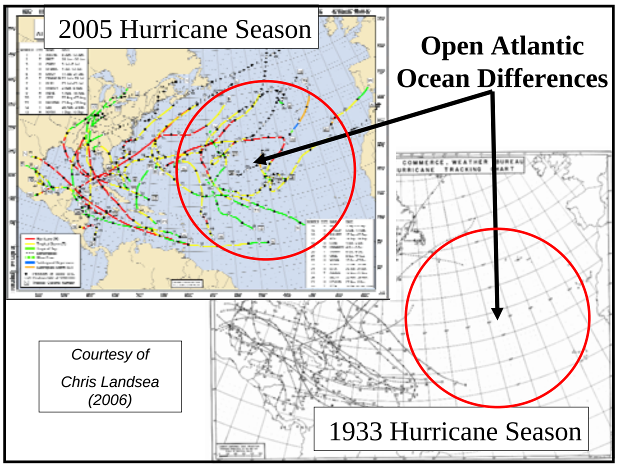
Source: Vecchi et al. *Science* (2008) 85

Eos, Vol. 88, No. 18, 1 May 2007

歷史資料的不確定性！

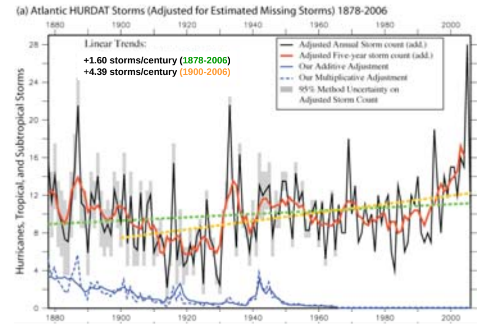
**Pre 1965 75%**
**Post 1965 59%**




*Courtesy of Chris Landsea (2006)*

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

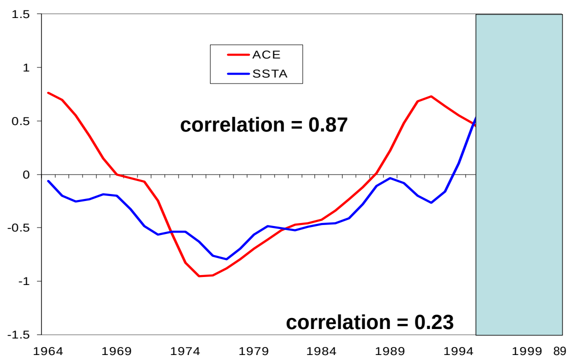



Trend from 1878-2006: Not significant (p=0.05, 2-sided tests, computed p-val ~0.2)
Trend from 1900-2006: Is significant at p=0.05 level

88

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

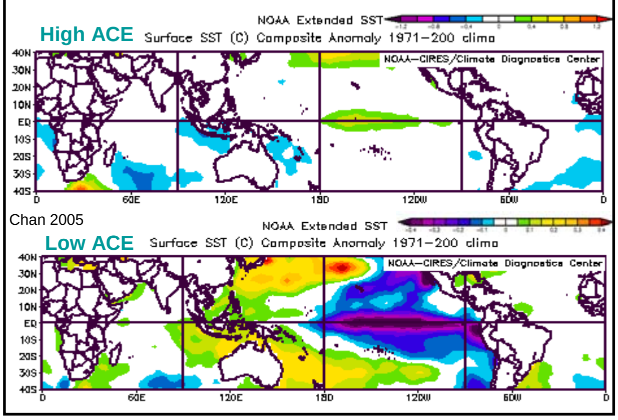
## ACE vs May-Nov SSTA (5-30°N, 120-180°E) [10-year Gaussian-filtered; standardized]




89

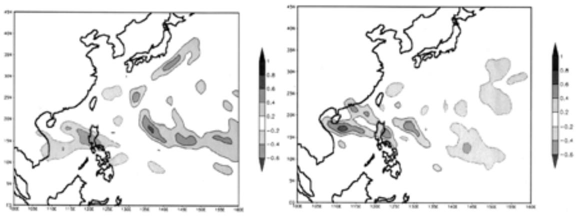
Chan 2005

## May-Nov SSTA; High vs. Low ACE (≥|0.5 $\sigma$ |)



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　　(b) La Niña years

91

< *Wu et al. 2004* >

## 臺灣氣候問題　季節、十年、百年尺度

颱風是關鍵

### 生成頻率是否有改變？

『目前大多數模式仍無法模擬颱風生成』

### 強度與生命期？

『目前大多數模式仍無法合理模擬颱風雙眼牆過程』
『生成區域與生成頻率之關係？』
『問颱風大小強度，誰主浮沈？』

### 臺灣未來降雨？

『目前大多數模式無法做出颱風合理雨量』

### 生成區域與路徑是否會改變？

『革命尚未成功，同志仍須努力。』

92

**20th Century**

**Geophysical Fluid Dynamics (GFD)**
Atmospheric Oceanic Fluid Dynamics (AOFD)
is for those interested in doing research in the physics, chemistry, and/or biology of Earth fluid environment.

Fig. 9.2 Karman vortex streets in (a) the laboratory, for water flowing past a cylinder [From M. Van Dyke, *An Album of Fluid Motion*, Parabolic Press, Stanford, Calif. (1982) p. 56.], and (b) in the atmosphere, for a cumulus-topped boundary layer flowing past an island [NASA MODIS imagery].

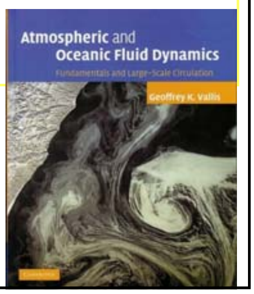



Fig. 9.2 Karman vortex streets in (a) the laboratory, for water flowing past a cylinder [From M. Van Dyke, *An Album of Fluid Motion*, Parabolic Press, Stanford, Calif. (1982) p. 56.], and (b) in the atmosphere, for a cumulus-topped boundary layer flowing past an island [NASA MODIS imagery].

## 問世間颱風是何物？

- 夫大塊噫氣、其名為風 -- 莊子齊物論
- 「颱」-- 明末清初17世紀首見於漢文
- 康熙年間台灣府奏摺：今年亢旱之後、繼以颱風
  今歲入秋亢旱、繼又颶風大作
  台澎海外地方、每直秋潮節候、颱颶時有
- Typhoon -- 英文字根為16世紀阿拉伯語Touffon（旋轉）
- Typhon -- 希臘神話的風神
- Kamikaze -- 神風（？）13世紀末蒙古征日

渦旋，旋轉流體
Vortex，Rotational Dynamics

角動量

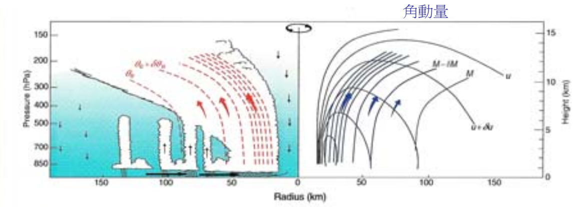


Fig. 8.78 Idealized radial cross section through an intense tropical cyclone showing the distributions of clouds, rain, radial flow and equivalent potential temperature ($\theta_e$) on the left and azimuthal wind speed and angular momentum on the right. The $\theta_e$ contours are congruent with angular momentum contours. [Adapted from *Atmospheric Circulation Systems: Their Structure and Physical Interpretation*, E. Palmén and C. W. Newton, p. 481, Copyright (1969), with permission from Elsevier. Modifications based on figures in *Mon. Wea. Rev.*, **104** (1976) 418–442.]

96

Fig. 8.76 The eye of Hurricane Isabel, passing to the northeast of Puerto Rico at 1315 UTC September 12, 2003. At this time Isabel was a category 5 storm with sustained winds of ~70 m s$^{-1}$. The eyewall cloud slopes radially outward with increasing height. Lower clouds within the eye itself are arranged in a symmetric pattern. [NOAA GOES-12 Satellite imagery.]

Fig. 8.77 The eye of Category-5 Hurricane Katrina late afternoon August 28, 2005 as viewed from an aircraft flying at an altitude ~3.5 km. The photograph was taken looking toward the east just to the south of the center of the eye. The darker clouds are shaded by the western eyewall cloud. The top of the eyewall cloud slopes radially outward with increasing height like the bleachers in a stadium. [Courtesy of Bradley F. Smull and RAINEX.]

97

颱風大小與強弱無明顯關係

**What are the controls??**

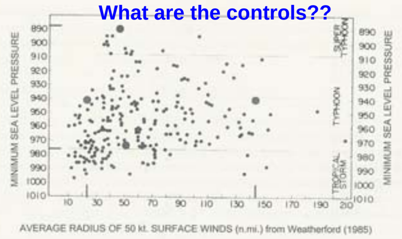



**Figure 13.** Intensity (minimum sea-level pressure) versus the radial extent of 50 kt (60 miles/hour) winds in nautical miles (n mi) for northwest Pacific typhoons as measured by reconnaissance aircraft [Weatherford and Gray 1988]. One n mi is equal to 1.85 km. Large dots illustrate the large differences that can exist for cyclones of the same minimum sea-level pressure (MSLP) of 940 mb, 23 kt versus 144 kt. Note also that the cyclones of similar outer radius of 50 knot winds can have MSLP differences as great as 890 versus 975 mb. These measurements are also typical of the Atlantic.

Weatherford and Gray 1988

98

象神颱風侵襲後的台北市

99

## 臺灣的颱風洪水災害

➢自1897年至2004年間侵臺颱風共計**401**次，平均每年達**3.75**次颱風。

➢近40年來颱風所造成之平均年損失達**174**億元，約爲國民生產毛額之**0.33%**。

➢臺灣與颱洪
- 有颱風有災害
- 無颱風無水用
- 颱風假經濟衝擊上百億

100

中央氣象局都卜勒氣象雷達網

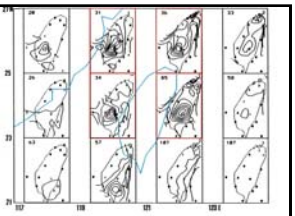

101

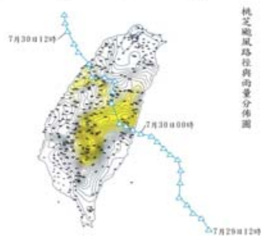
24至36小時前有能力預測數十至近百公里豪大雨區域（地形鎖住效應）

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

**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

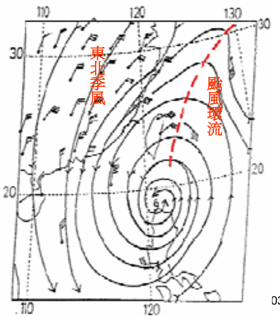




颱風與其它天氣系統交互作用形成豪雨

共伴環流形成槽線及豪雨，這種共伴最常發生於10-11月的颱風（俗稱爲「秋颱」）個案。

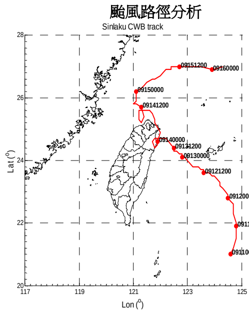
其他天氣系統影響預估雨量

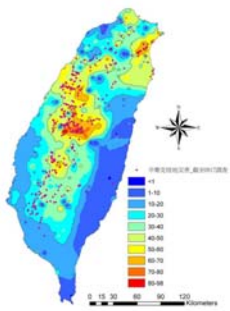



03

## 2008年辛樂克颱風造成台灣重大災情

- 總計發佈101報颱風警報。
- 歷時126小時
- 行徑詭異、移動速度相當緩慢。



104

## 颱風科學研究四大方向

路徑： Track error cut half since 1990
衛星資料、數值模式與資料同化的大幅改進

強度 風切 冷空氣 洋溫 暖水層
雙眼牆 眼牆渦度混合

生成 跨尺度問題(每隔7、8天)連續生成

颱風與氣候 生成頻率 生成區域 強度 反饋
水循環

105

Politics are for the moment
An equation is for eternity


但覺高歌有鬼神
不知餓死填溝壑

熱力學 ＋ 流體力學

Euler 1755

$$\frac{d}{dt}\int_{v_m}\rho\vec{v}\,dv = -\int_{\partial v_m} p\,d\vec{s}$$

$$\int_{v_m}\rho\frac{d\vec{v}}{dt}\,dv = -\int_{v_m}\nabla p\,dv$$

$$\rho\frac{d\vec{v}}{dt} = -\nabla p$$

Lagrange 1781

$$\frac{\partial\vec{u}}{\partial t} + \vec{\zeta}\times\vec{u} = -\frac{1}{\rho}\nabla p - \nabla K - \nabla\Phi$$

Rotation Vortex

Lorentz Force Law

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v}\times\mathbf{B})$$

$$\mathbf{F} = q(-\nabla V + \mathbf{v}\times\mathbf{B})$$

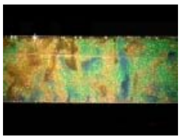
07

旋轉
Rotation

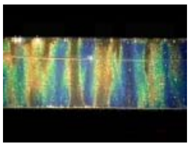
Coriolis Force

Non-inertial Frame

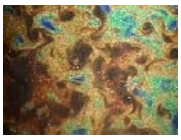
3D

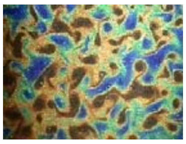


2D (strong rotation)



Taylor columns Vortex Tubes





Vortices with sharp edge



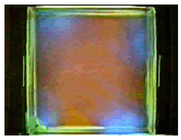
Kyoto Univ. GFD group

Waves with zero potential vorticity

Non-rotation

rotation

rotation

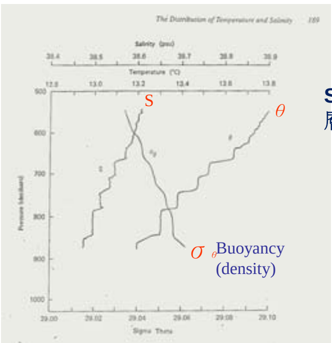


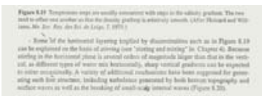
Gravity waves

Kelvin Waves
Edge waves



Ocean Spice



Stratification
層化

$\sigma_\theta$ Buoyancy (density)



Multiple Scale Interactions in Vortex

Wave mean flow interaction in stable stratified fluid
Turbulent feed back to the vortex mean flow

2D turbulence



## 2D Turbulence

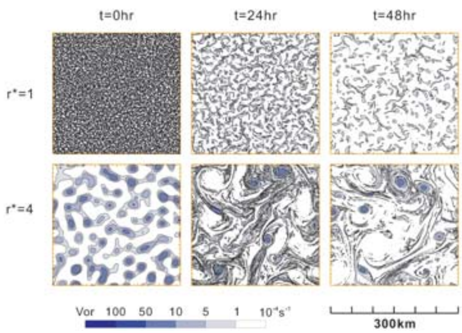
**Stratification and/or Rotation**
**Vortex Waves Turbulence**

$$\frac{\partial \zeta}{\partial t} + u\frac{\partial \zeta}{\partial x} + v\frac{\partial \zeta}{\partial y} = \nu \nabla^2 \zeta$$

$$u = -\frac{\partial \psi}{\partial y}, \quad v = \frac{\partial \psi}{\partial x}.$$

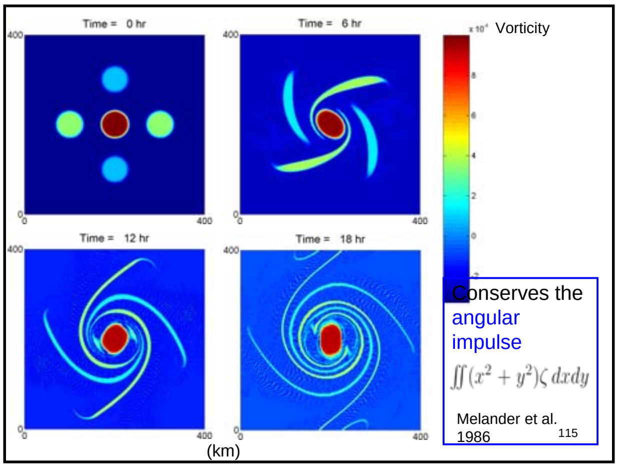
$$\frac{\partial \zeta}{\partial t} + \frac{\partial(\psi, \zeta)}{\partial(x, y)} = \nu \nabla^2 \zeta$$

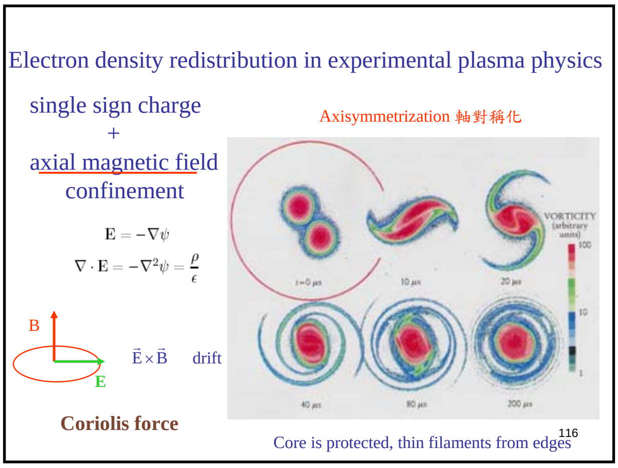


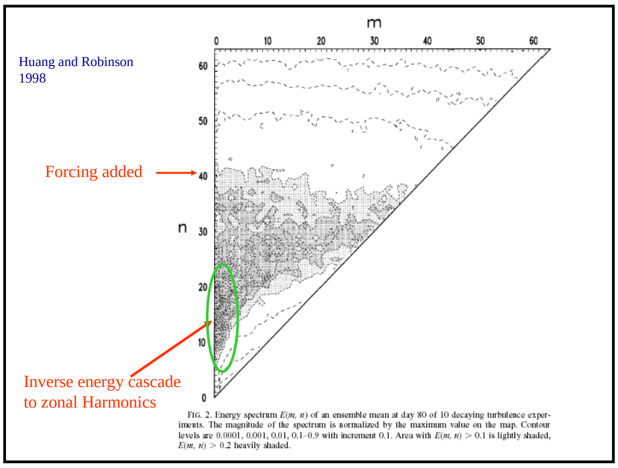


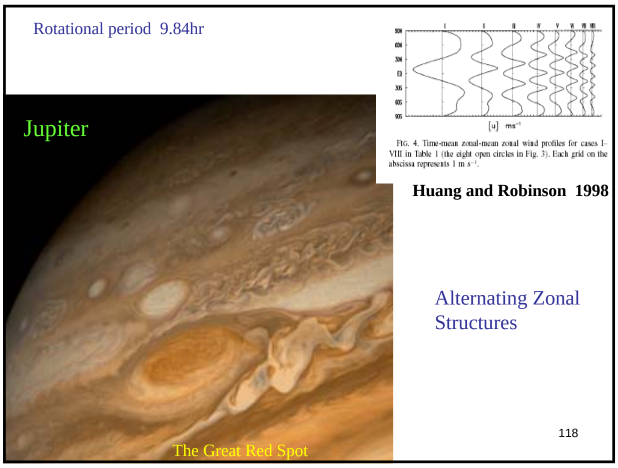

小尺度變大尺度

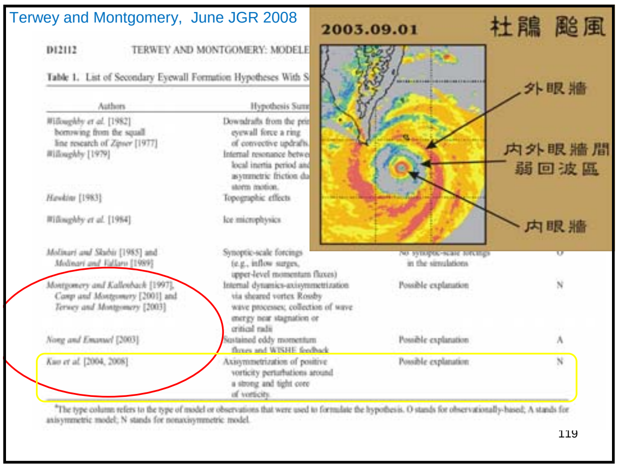
**Fewer and stronger vortices !!!**
**Coherent structure with filamentations in 2-D turbulence**

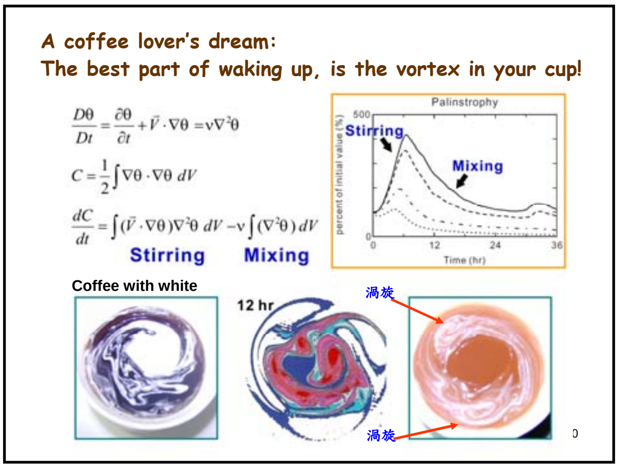

Time = 0 hr
Time = 6 hr
Time = 12 hr
Time = 18 hr
Vorticity
Conserves the angular impulse
$\iint (x^2+y^2)\zeta\, dxdy$
Melander et al. 1986
(km)
115


Electron density redistribution in experimental plasma physics
single sign charge
+
axial magnetic field confinement
$E = -\nabla\psi$
$\nabla \cdot E = -\nabla^2\psi = \frac{\rho}{\epsilon}$
B
E
$\vec{E}\times\vec{B}$ drift
Coriolis force
Axisymmetrization 軸對稱化
VORTICITY (arbitrary units)
Core is protected, thin filaments from edges
116


Huang and Robinson 1998
Forcing added
Inverse energy cascade to zonal Harmonics
m
n
FIG. 2. Energy spectrum E(m, n) of an ensemble mean at day 80 of 10 decaying turbulence experiments. The magnitude of the spectrum is normalized by the maximum value on the map. Contour levels are 0.0001, 0.001, 0.01, 0.1–0.9 with increment 0.1. Area with E(m, n) > 0.1 is lightly shaded, E(m, n) > 0.2 heavily shaded.


Rotational period 9.84hr
Jupiter
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.
Huang and Robinson 1998
Alternating Zonal Structures
The Great Red Spot
118


Terwey and Montgomery, June JGR 2008
2003.09.01
杜鵑 颱風
外眼牆
內外眼牆間弱回波區
內眼牆
D12112 TERWEY AND MONTGOMERY: MODELE
Table 1. List of Secondary Eyewall Formation Hypotheses With S
Montgomery and Kallenbach [1997], Camp and Montgomery [2001] and Terwey and Montgomery [2003]
Internal dynamics-axisymmetrization via sheared vortex Rossby wave processes; collection of wave energy near stagnation or critical radii
Possible explanation
Nong and Emanuel [2003]
Sustained eddy momentum fluxes and WISHE feedback
Kuo et al. [2004, 2008]
Axisymmetrization of positive vorticity perturbations around a strong and tight core of vorticity
119


A coffee lover's dream:
The best part of waking up, is the vortex in your cup!
$\frac{D\theta}{Dt} = \frac{\partial\theta}{\partial t} + \vec{V}\cdot\nabla\theta = \nu\nabla^2\theta$
$C = \frac{1}{2}\int \nabla\theta\cdot\nabla\theta\, dV$
$\frac{dC}{dt} = \int(\vec{V}\cdot\nabla\theta)\nabla^2\theta\, dV - \nu\int(\nabla^2\theta)\, dV$
Stirring Mixing
Palinstrophy
Stirring
Mixing
percent of initial value (%)
Time (hr)
Coffee with white
12 hr
渦旋
渦旋

Bowmen and Mangus (1993)

## 臭氧洞衛星觀測

Observations of deformation and mixing of the total ozone field in the Antarctic polar vortex

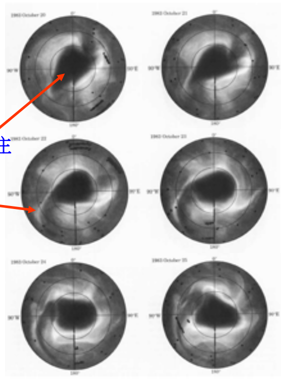
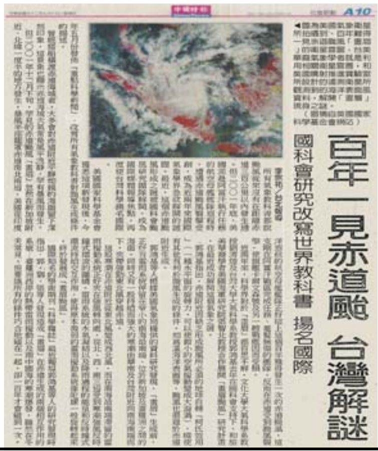



Fig.1: Daily TOMS images of total ozone in the Southern Hemisphere for six consecutive days in October 1983. Latitude circles are drawn at 40˚,60˚, and 80 ˚S. The outermost latitude is 20 ˚S.

121



A10

# 百年一見赤道颱 台灣解謎

## 國科會研究改寫世界教科書 揚名國際

122