6.8 台风强度指数

台风强度指数

✓ **强度突变指数**（Kaplan and DeMaria 2003）

Rapid Intensification Index（RII）

- 台风强度在未来24小时强烈发展（24小时内增加15米/秒或以上）的可能性
- 业务应用

Atlantic & E. Pacific since 2006

Western Pacific since 2018

台风强度指数

- ✓ 双眼墙形成指数（Kossin et. al.，2006）
  Secondary Eyewall Formation Index（SEFI）
- ✓ 环状飓风指数（Cram et al. 2006 ）Annular Hurricane Index （AHI）
- ✓ 风暴垂直切变倾向（Gallina and Velden 2002）
  Storm Relative Shear Tendency
- ✓ 台风变性指数（Sarah C. Jones, Patrick A. Harr, Jim Abraham等，2003）
  Extra Tropical Transition Index（ETI)

● 强度突变指数

Rapid Intensification Index （RII）

Predictors used in operational NHC SHIPS-RII			
	Predictor	Definition	More Favorable
1	PER	Previous 12-h intensity change	Larger
2	VMAX	Maximum sustained wind (t=0h)	Avg. of RI sample
3	IRSD	Std. dev. of 50-200km IR brightness temperatures (t= 0h)	Smaller
4	IRPC	2nd principle component of IR image (0-440 km radius) (t= 0h)	Front left quadrant
5	SHEAR	850-200hPa shear 0-500 km radius	Smaller
6	D200	200hPa divergence from 0-1000 km radius (time-avg.)	Larger
7	TPW	Percent area with total precipitable water (TPW) < 45 mm within 500km 90 deg. up-shear (t=0h)	Smaller
8	CFLX	Inner-core dry-air predictor/flux	Smaller
9	POT	Potential intensity ((time-avg.)	Larger
10	OHC	Oceanic heat content (time-avg.)	Larger
3 new predictors		RMW Objective Storm Size R5 (Knaff et al. 2014) Sine of Latitude	

- **强度突变指数 Rapid Intensification Index（RII）**

  2018/2019 NHC Operational Statistical RI models

✓ Predict RI probability for **8 RI thresholds** at **4 lead times** (20kt/12h, 25kt/24h, 30kt/24h, 35kt/24h, 40kt/24h, 45kt/36h, 55kt/48h and 65kt/72h) for Atlantic and E. Pacific

● 强度突变指数 Rapid Intensification Index（RII）

2018/2019 NHC Operational Statistical RI models

✓ Multi-lead time RI models developed include the following

① SHIPS-RII (Kaplan et al. 2015)

- Based upon linear discriminant analysis
- 10 SHIPS environmental predictors utilized in both Atlantic and E. Pacific basins

② Logistic regression and Bayesian RI models

(Rozoff and Kossin 2011; Kaplan et al. 2015)

强度突变指数 Rapid Intensification Index（RII）

2018/2019 NHC Operational Statistical RI models

✓ Multi-lead time RI models developed include the following

③ **Consensus RI model**

- The arithmetic average of SHIPS, Logistic, and Bayesian models

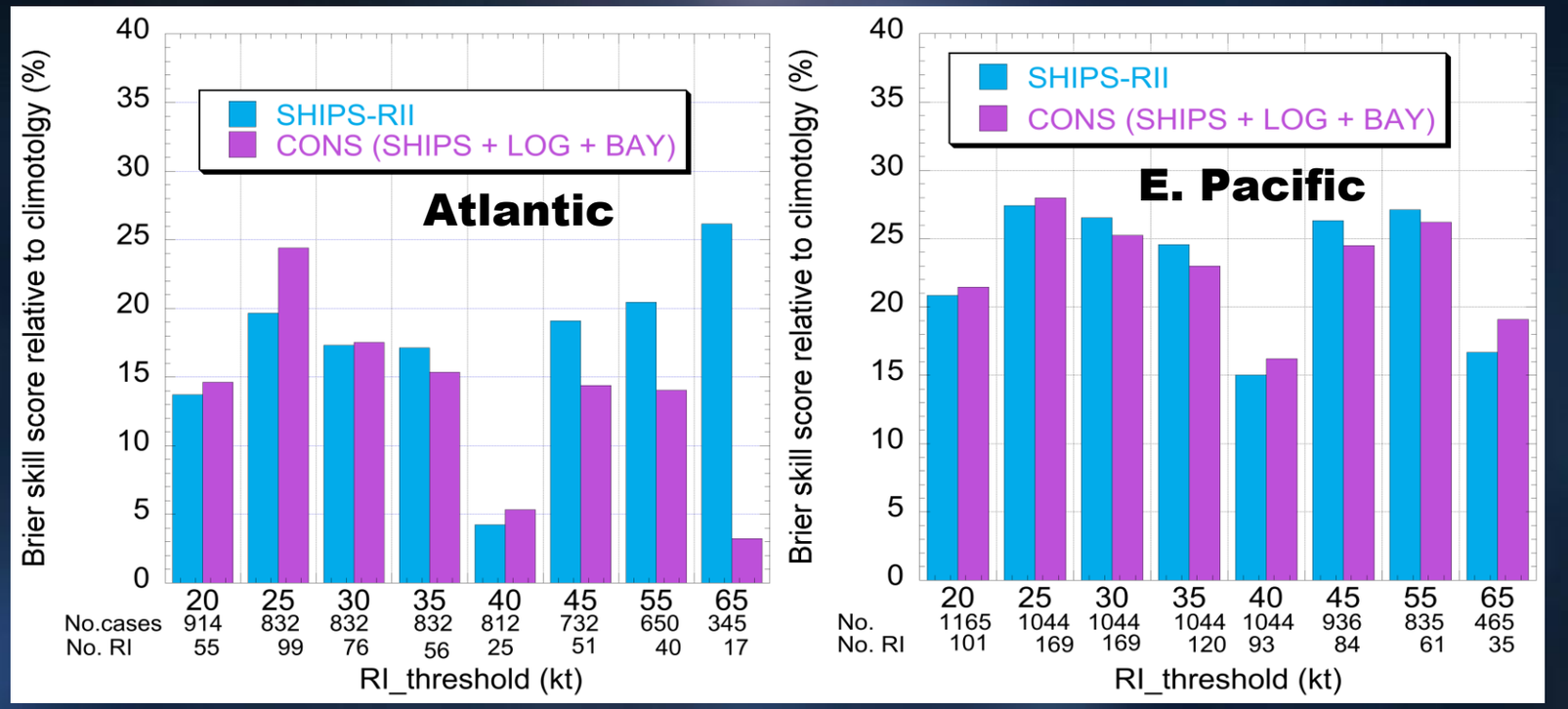
④ **Probabilistic Statistical Rapid Intensification Index (DTOPS)**

(Matthew Onderlinde & M. DeMaria，2018)

- Based on logistic regression, ECMWF, GFS, HWRF, LGEM, and SHIPS

强度突变指数 Rapid Intensification Index （RII）

2016-2018 NHC Operational Statistical RI models



Skill of the 2016-2018 Operational RI model Forecasts

强度突变指数 Rapid Intensification Index （RII）

2018/2019

NHC Operational Statistical RI Product

CURRENT MAX WIND (KT): 75. LAT, LON: 21.0 66.9

** 2019 ATLANTIC RI INDEX AL052019 DORIAN 08/29/19 12 UTC **
(SHIPS-RII PREDICTOR TABLE for 30 KT OR MORE MAXIMUM WIND INCREASE IN NEXT 24-h)

Predictor		Value	RI Predictor Range			Scaled Value(0-1)	% Contribution
12 HR PERSISTENCE (KT)	:	5.0	-49.5	to	33.0	0.66	6.3
850-200 MB SHEAR (KT)	:	7.0	30.1	to	2.3	0.83	3.0
HEAT CONTENT (KJ/CM2)	:	60.0	0.0	to	151.8	0.40	1.2
STD DEV OF IR BR TEMP	:	16.9	36.6	to	2.8	0.58	2.3
MAXIMUM WIND (KT)	:	75.0	22.5	to	137.5	0.81	1.7
2nd PC OF IR BR TEMP	:	1.0	2.9	to	-2.9	0.32	0.8
POT = MPI-VMAX (KT)	:	71.3	27.5	to	139.6	0.39	1.0
D200 (10**7s-1)	:	31.2	-29.7	to	185.9	0.28	0.3
%area of TPW <45 mm upshear	:	41.5	100.0	to	0.0	0.58	0.0
BL DRY-AIR FLUX (W/M2)	:	439.4	895.4	to	-55.0	0.48	0.0

预报因子

SHIPS Prob RI for 20kt/ 12hr RI threshold= 11% is 2.2 times climatological mean (5.2%)
SHIPS Prob RI for 25kt/ 24hr RI threshold= 23% is 2.1 times climatological mean (10.9%)
SHIPS Prob RI for 30kt/ 24hr RI threshold= 17% is 2.4 times climatological mean (6.9%)
SHIPS Prob RI for 35kt/ 24hr RI threshold= 13% is 3.1 times climatological mean (3.8%)
SHIPS Prob RI for 40kt/ 24hr RI threshold= 12% is 5.6 times climatological mean (2.4%)
SHIPS Prob RI for 45kt/ 36hr RI threshold= 13% is 2.9 times climatological mean (4.5%)
SHIPS Prob RI for 55kt/ 48hr RI threshold= 16% is 3.4 times climatological mean (4.6%)
SHIPS Prob RI for 65kt/ 72hr RI threshold= 18% is 3.3 times climatological mean (5.4%)

Matrix of RI probabilities

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS-RII:	11.3%	23.3%	16.6%	13.3%	12.1%	13.0%	15.5%	17.6%
Logistic:	4.7%	23.5%	14.5%	9.5%	5.4%	17.9%	14.4%	14.2%
Bayesian:	2.5%	7.8%	2.1%	0.2%	0.1%	1.8%	2.6%	0.2%
Consensus:	6.2%	18.2%	11.0%	7.7%	5.9%	10.9%	10.8%	10.7%
DTOPS:	11.0%	25.0%	17.0%	8.0%	4.0%	12.0%	8.0%	7.0%

RII

2019年五级飓风“多里安”（Dorian）
美国国家飓风中心强度突变指数产品

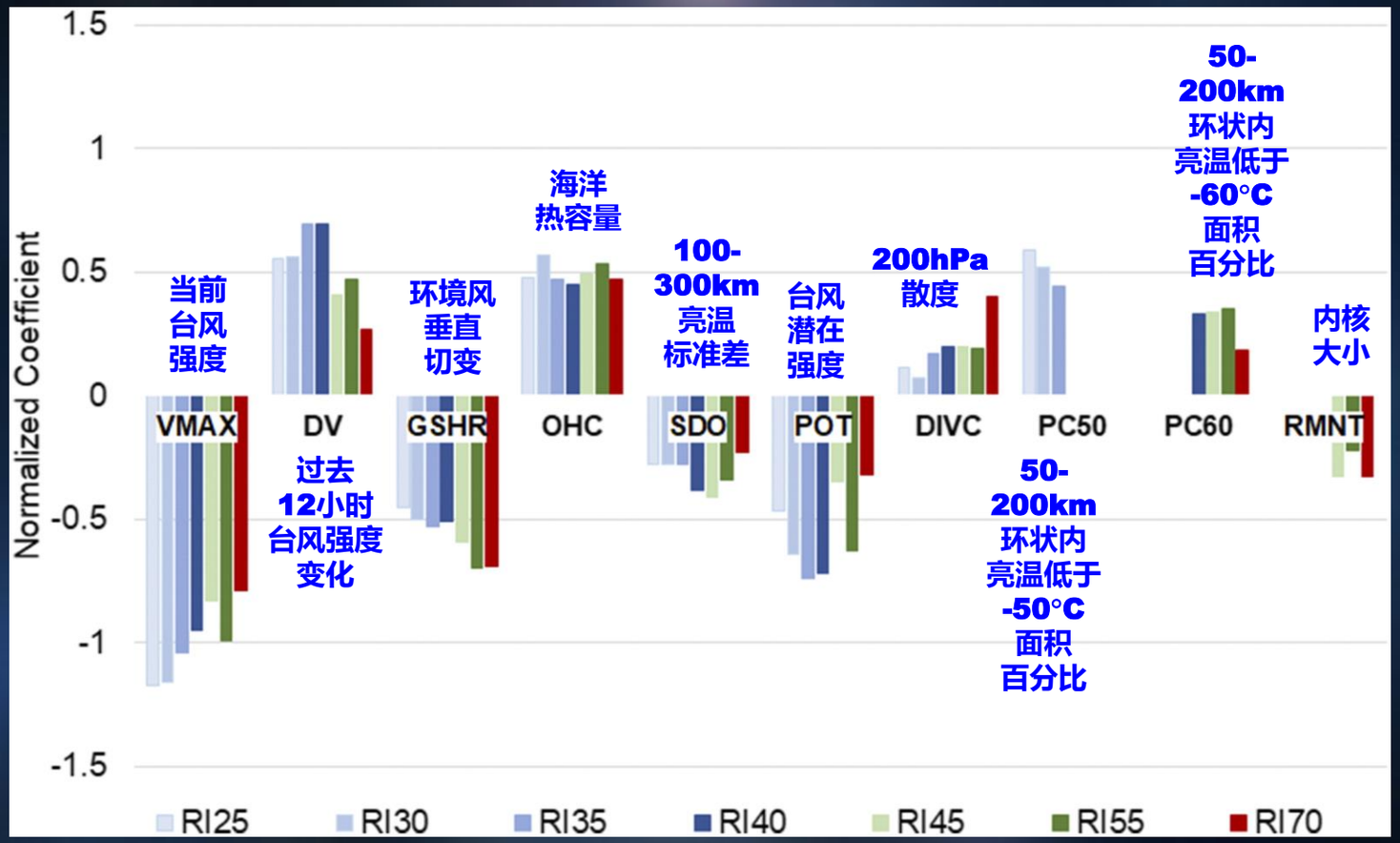
强度突变指数 Rapid Intensification Index（RII）

Predictors used in operational JTWC SHIPS-RII (Knaff et al. 2018)		
	Predictor	**Definition**
Environmental predictors (time averaged from t=0 to the forecast time)		
1	GSHR	850-200hPa generalized wind shear in a 200-800km annulus (Knaff et al.2005)
2	OHC	Oceanic heat content (Shay et al. 2000)
3	RHMD	700-500hPa relative humidity averaged within 200-800km annulus
4	DIVC	200hPa divergence in 500km circle centered on the TC
5	POT	Potential intensity (at t=0)
6	REFC	Average relative eddy momentum flux convergence ($ms^{-1}day^{-1}$) in 100-600km
7	TADV	Temperature advection between 850 and 700hPa averaged from 0 to 500km
Satellite IR predictors		
8	PC50	Percentage of IR pixels colder than -50°C within a 50-200km annulus
9	PC60	Percentage of IR pixels colder than -60°C within a 50-200km annulus
10	SDO	Standard deviation of IR brightness temperature at 100-300km
11	RMNT	Radius of minimum brightness temperature (0-150km)
13	FR5	Deviation of IR-based TC size (R5) from the climatological population
Best-track/advisory-based predictors		
14	VMAX	Current TC intensity (t=0)
15	DV	12h change in TC intensity, which is limited by the following function: DV=min[min(VMA×0.33, 17.5), DV]

强度突变指数 Rapid Intensification Index （RII）

Predictors used in operational JTWC SHIPS-RII

(Knaff et al. 2018)

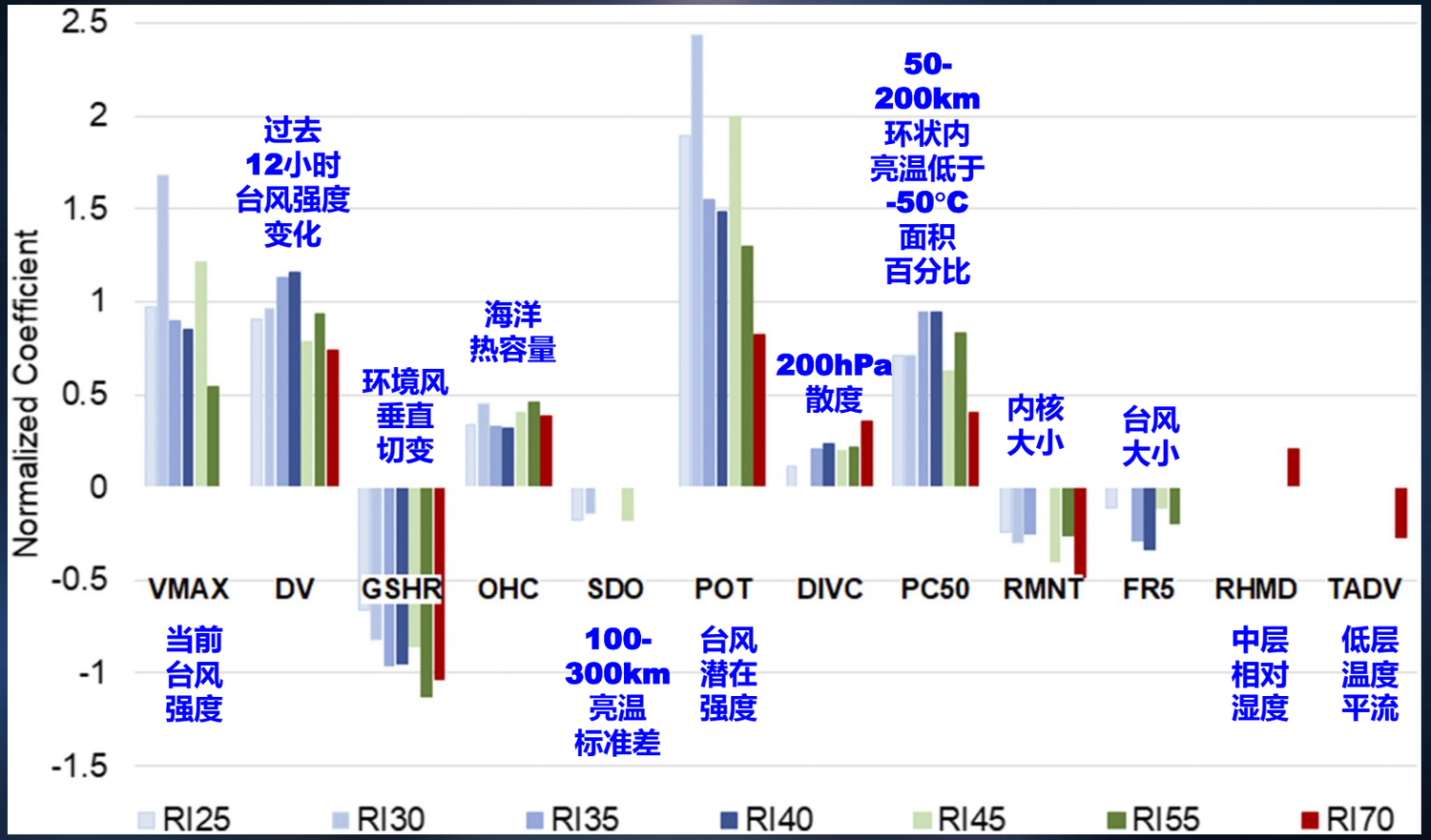


Normalized discriminant function coefficients for linear discriminant analysis (LDA)

强度突变指数 Rapid Intensification Index （RII）

Predictors used in operational JTWC SHIPS-RII

(Knaff et al. 2018)

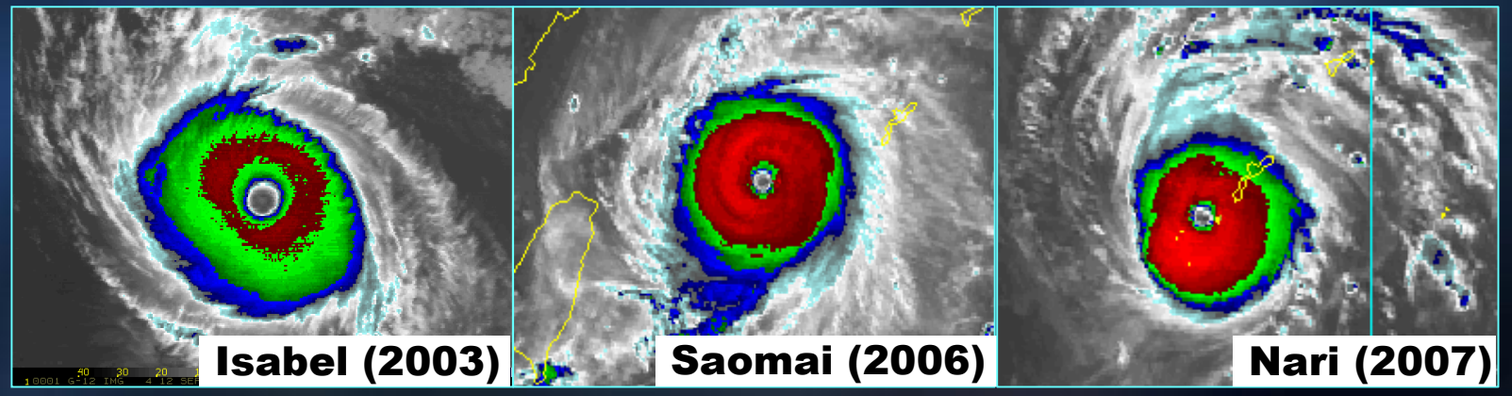


Normalized discriminant function coefficients for logistic regression(LRE)

环状飓风指数 Annular Hurricane Index（AHI）

✓ 环状飓风的结构

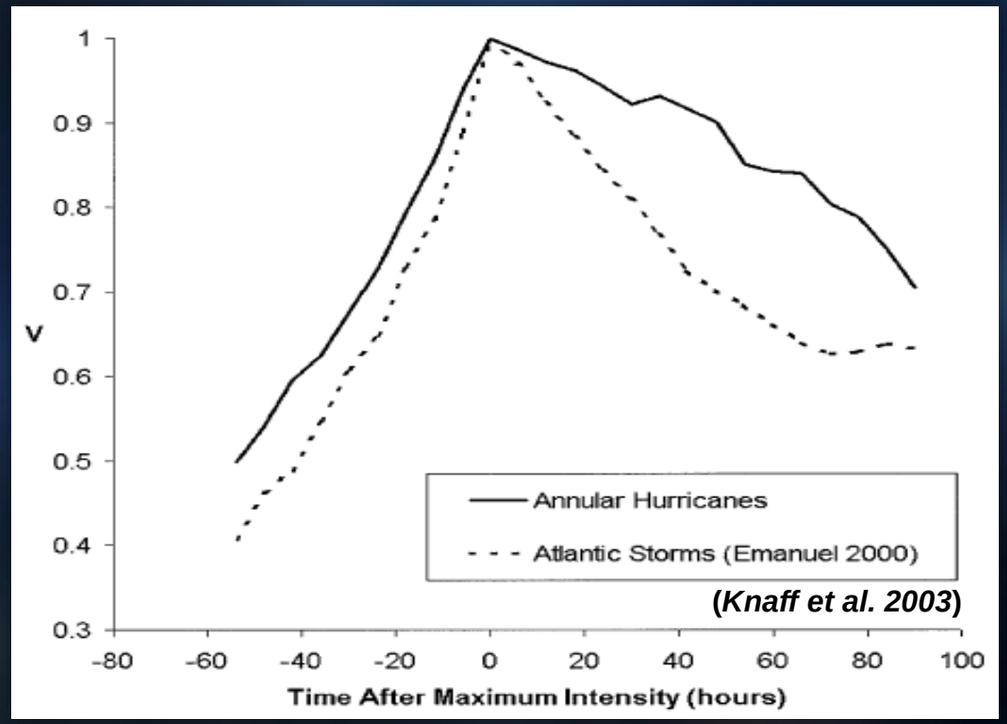
- Distinctly axisymmetric
- Large circular eyes
- Greatly reduced rainband activity
- Lasts at least 3 hours
- Rare, occur ~4% of the time
- ~4% Western Pacific 2000-2009 (Chu & Tan, 2014)
- East Pacific 3% and Atlantic 0.8% 1989–1999



● 环状飓风指数 Annular Hurricane Index（AHI）

✓ 环状飓风强度特点

- Do not weaken rapidly after max intensity
- Intensity is very close to 85% MPI with respect to SST
- Have large intensity biases & larger than normal intensity errors



(*Knaff et al. 2003*)

● 环状飓风指数 Annular Hurricane Index（AHI）

✓ 环状飓风形成的环境条件

- Weak Easterly/Southeasterly Wind Shear
- Weak Relative Eddy Flux Convergence
- 200hPa Easterlies
- SSTs in a range 25.4 to 28.6°C steady or decreasing.
- Weak Easterly shear, under an upper ridge, over SST <28.6°C
- Intensity > 85kt

● 环状飓风指数 Annular Hurricane Index（AHI）

✓ 环状飓风指数的计算

Subjective Diagnostic	Objective Parameter	Source
Large eyewall radius	R_c	IR Imagery
Warm Eye	ΔT_{eye}	IR Imagery
Vertical shear	SHRD	NCEP analysis
200 hPa winds	U200	NCEP analysis
Eddy flux convergence	REFC	NCEP analysis
SST	SST	Reynolds SST
Intensity	Intensity	NHC Best Track

Yellow = Structure　　Blue = Environment

REFC: Relative Eddy Momentum Flux Convergence

$$REFC = -r^{-2}\frac{\partial}{\partial r}(r^2\overline{U_L'V_L'})$$

r is the radius from storm center, *U* is the radial wind, *V* is the tangential wind, the overbar represents an azimuthal average with respect to storm center, the primes represent deviations from that average, and the subscript *L* indicates a coordinate system moving with the storm.

● 环状飓风指数 Annular Hurricane Index（AHI）

✓ 环状飓风指数的计算

① 筛查（Screening）

Parameter	Prescreening Criterion
Intensity	< 84kt
R_c	< 50km
ΔT_{eye}	< 15°C
SHRD	> 11.3 ms^{-1}
U200	< -11.8 or > 1.5 ms^{-1}
REFC	< -9 or > 11 ms^{-1} day^{-1}
SST	< 24.3 or > 29.1 °C

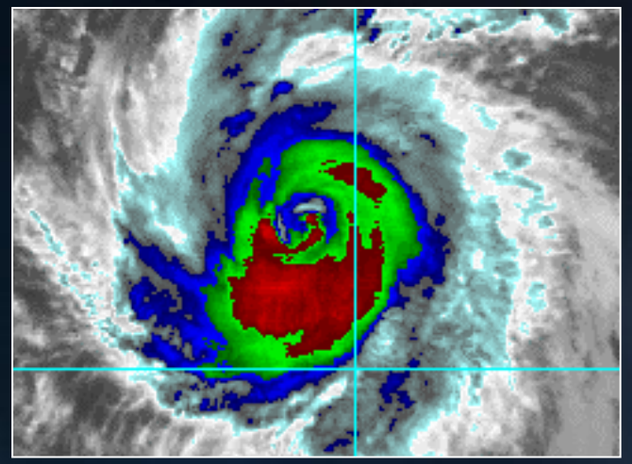
✓ 环状飓风指数的计算

② 线性判别分析 --- 机器学习方法之一

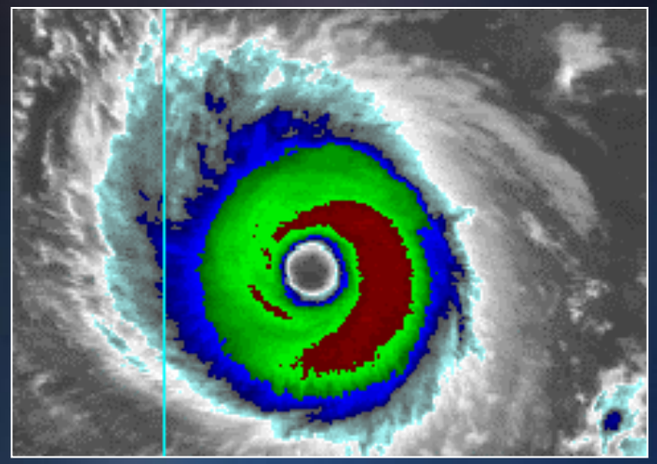
Linear Discriminant Analysis(LDA)

Annular Hurricane Index EP052006 07/22/2006 00 UTC			
Parameter	Observation	Criterion	Passed or not
Screening Storm Intensity	= 130kt	> 84kt ?	---> Passed
Screening SST	= 27.3°C	> 24.3°C ?	---> Passed
Screening SST	= 27.3°C	< 29.1°C ?	---> Passed
Screening Vertical Shear	= 5.7kt	< 21.97 kt ?	---> Passed
Screening 200hPa Zonal Wind	= -13.2kt	> -22.94 kt ?	---> Passed
Screening 200hPa Zonal Wind	= -13.2kt	< 2.92 kt ?	---> Passed
Screening 200hPa Mom Flux Conv	= -0.1m/s-day	> -9m/s-day ?	---> Passed
Screening 200hPa Mom Flux Conv	= -0.1m/s-day	< 11m/s-day ?	---> Passed
Screening Goes Rad Cold Br Temp	= 106km	> 50km ?	---> Passed
Screening Goes Eye-ring Br Temp	= 16.2°C	> 15°C ?	---> Passed
Storm may be annular, passed screening Calculate AHI from discriminant analysis			
Annular Hurricane Index (AHI) Value = 100. (AHI = 100. is best match to annular structure) (AHI = 1. is worst match to annular structure) (AHI = 0. for no annular structure)			

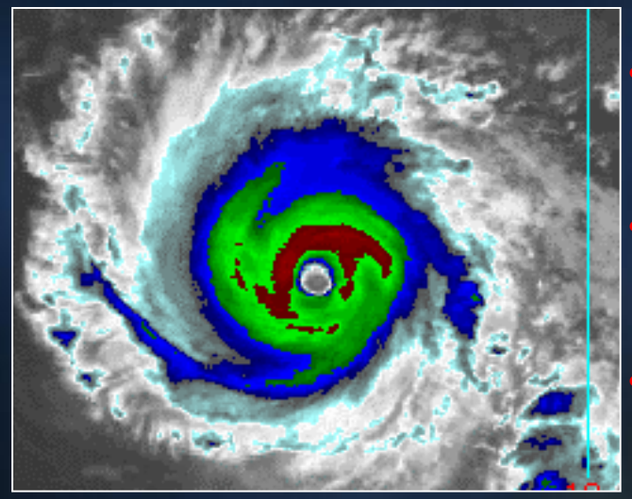
环状飓风指数 --- 四级飓风Daniel（2006）示例



7/20/06 0Z, Vmax= 95kt
AHI = 0



7/22/06 0Z Vmax = 130kt
AHI = 100



7/21/06 0Z, Vmax= 120kt
AHI = 50

- AHI = 0
  → No annular structure
- AHI = 1
  → Worst match to annular structure
- AHI = 100
  → Best match to annular structure

● 环状飓风指数 Annular Hurricane Index（AHI）

2018/2019
NHC Operational Statistical AHI Product

```
        ANNULAR HURRICANE INDEX (AHI) AL052019 DORIAN     08/29/19  12 UTC
STORM NOT ANNULAR, SCREENING STEP FAILED, NPASS=3 NFAIL=4
AHI=  0   (AHI OF 100 IS BEST FIT TO ANN. STRUC., 1 IS MARGINAL, 0 IS NOT ANNULAR)
```

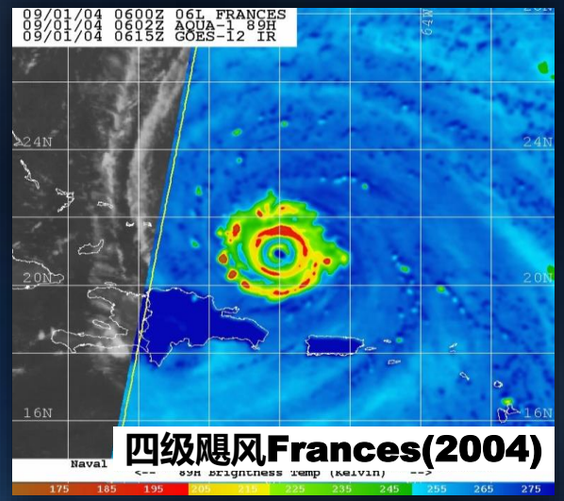
2019年五级飓风“多里安”（Dorian）
美国国家飓风中心环状飓风指数产品
ftp://ftp.nhc.noaa.gov/atcf/stext

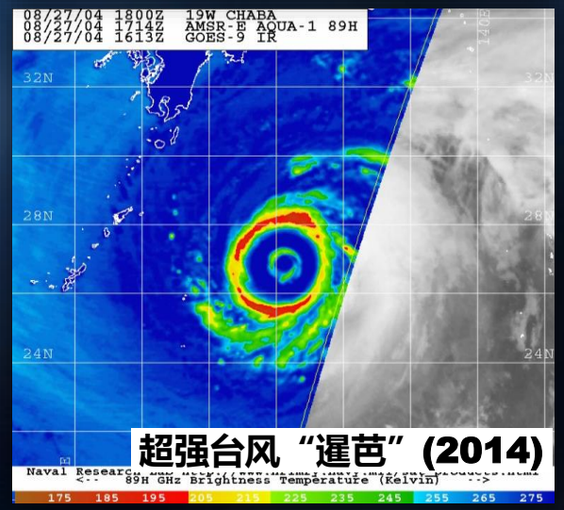
双眼墙形成指数

Secondary Eyewall Formation Index（SEFI）

双眼墙台风特点

- ✓ Precursors to large and rapid intensity and structure changes
- ✓ Often interrupt intensification, sometimes briefly, sometimes permanently
- ✓ Wind field expands: wind radii, storm surge, and integrated kinetic energy all increase
- ✓ Present a unique forecast challenge, but no objective guidance available





双眼墙形成指数

Secondary Eyewall Formation Index（SEFI）

Predictors used in operational NHC SEFI			
	Predictor	Definition	Preference for SEF
1	VMX	Current intensity	Stronger
2	LAT	Latitude	Further south
3	D26C	Climatological depth of 26°C ocean	Deeper
4	U200	200hPa zonal wind (200–800 km from center)	Weaker (near zero), very narrow range
5	RHHI	500-300hPa relative humidity	Moister
6	TWAC	0-600km average symmetric tangential wind at 850hPa	Stronger
7	PENC	Azimuthally averaged surface pressure at outeredge of vortex	Lower
8	SHRD	850–200-hPa shear magnitude	Weaker, narrow range
9	VMPI	Maximum potential intensity	Higher, very narrow range
10	IR00–05	Standard deviation (from axisymmetry) of infrared brightness temperature between 100 and 300km	Smaller (more axisymmetric)
11	IR00–16	Average infrared brightness temperature between 20 and 120km	Colder, narrow range

双眼墙形成指数

Secondary Eyewall Formation Index（SEFI）

✓ **P**robability of **S**econdary **E**yewall **F**ormation (**PSEF**)

- Executes within SHIPS using environmental and satellite-based features as input
- Probability of secondary eyewall formation, given a collection **F** of observed features (storm, environment, satellite)
- Provides probability of the onset of an eyewall Formation at lead-times: 0−12h, 12−24h, 24−36h, 36−48h

$$P(C_{\text{sef}}|\mathbf{F}) = \frac{P(C_{\text{sef}})P(\mathbf{F}|C_{\text{sef}})}{P(\mathbf{F})}$$

双眼墙形成指数

Secondary Eyewall Formation Index（SEFI）

2018/2019

NHC Operational Statistical PSEF Product

```
** PROBLTY OF AT LEAST 1 SCNDRY EYEWL FORMTN EVENT AL052019 DORIAN     08/29/2019  12 UTC *
TIME(HR)    0-12   12-24(0-24)   24-36(0-36)   36-48(0-48)
CLIMO(%)       5       8( 13)       11( 22)       16( 35)     <-- PROB BASED ON INTENSITY ONLY
PROB(%)        0       1(  1)        0(  1)        1(  2)     <-- FULL MODEL PROB (RAN NORMALLY)
```

2019年五级飓风“多里安”（Dorian）

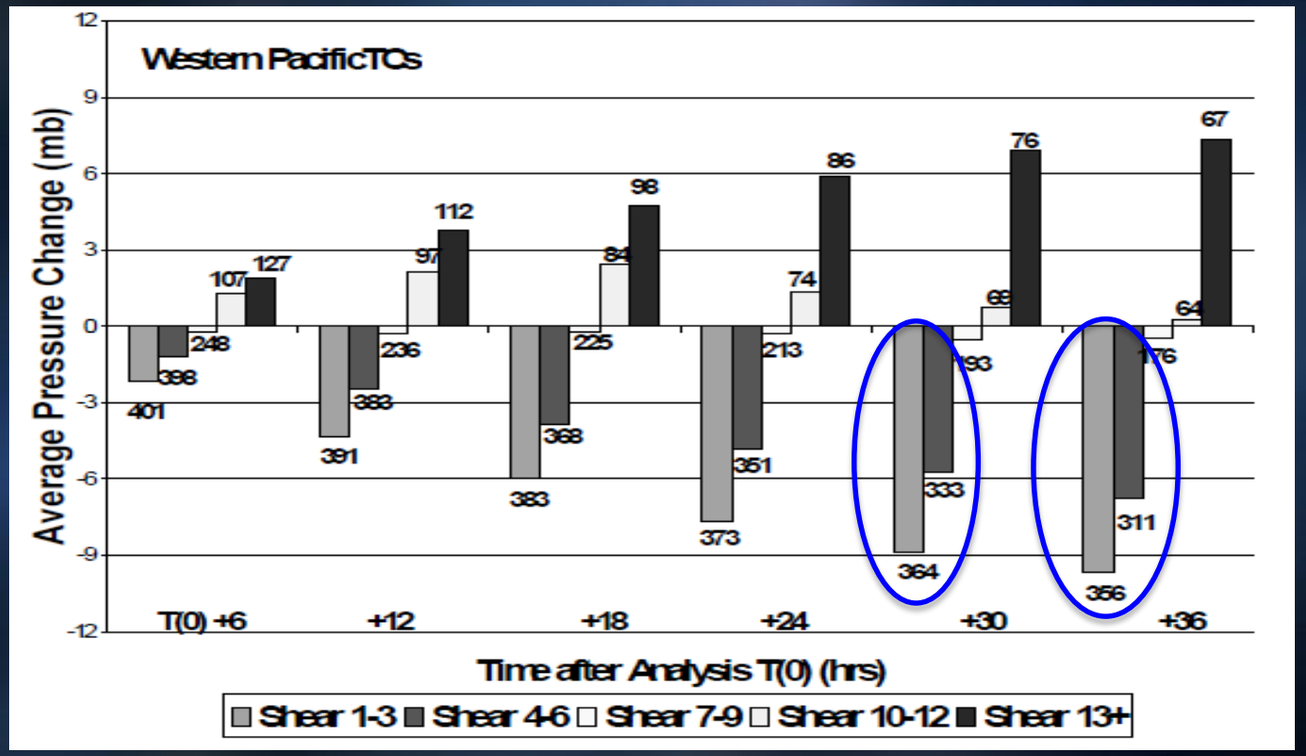
美国国家飓风中心双眼墙形成指数产品

ftp://ftp.nhc.noaa.gov/atcf/stext

风暴垂直切变倾向

Storm Relative Shear Tendency

- 西北太平洋，环境垂直切变临界值约为9-10米/秒
  - ① 环境垂直切变大于9-10米/秒时，一般趋于减弱
  - ② 环境垂直切变小于9-10米/秒时，一般趋于加强或维持



西太平洋台风强度变化与环境风垂直切变的关系

台风变性指数

Extra Tropical Transition Index（ETI）

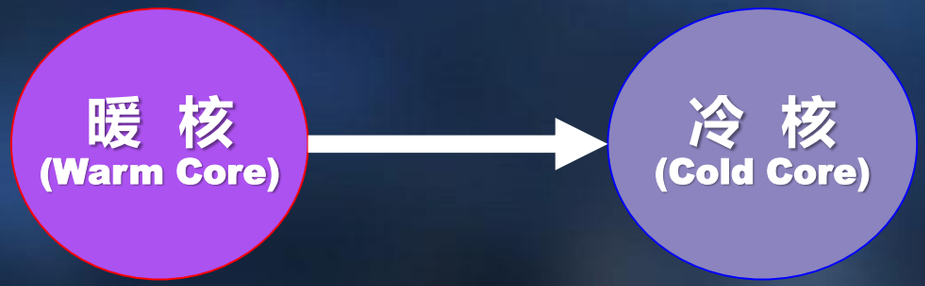
- ✓ Structural unknowns, the cyclone having originated and tracked over oceanic/data sparse areas
- ✓ Rapid changes in this structure that occur during the transformation phase
- ✓ ET is a complex evolutionary process that involves interactions over a variety of horizontal and vertical scales
- ✓ Some of the physical processes of ET are as yet still uncertain
- ✓ ET process is poorly understood and incompletely researched
- ✓ A universal definition of ET does not exist

● 台风变性指数

Extra Tropical Transition Index（ETI）

✓ 热力非对称性指数（Thermal Asymmetry）

✓ 热成风指数（Thermal wind）

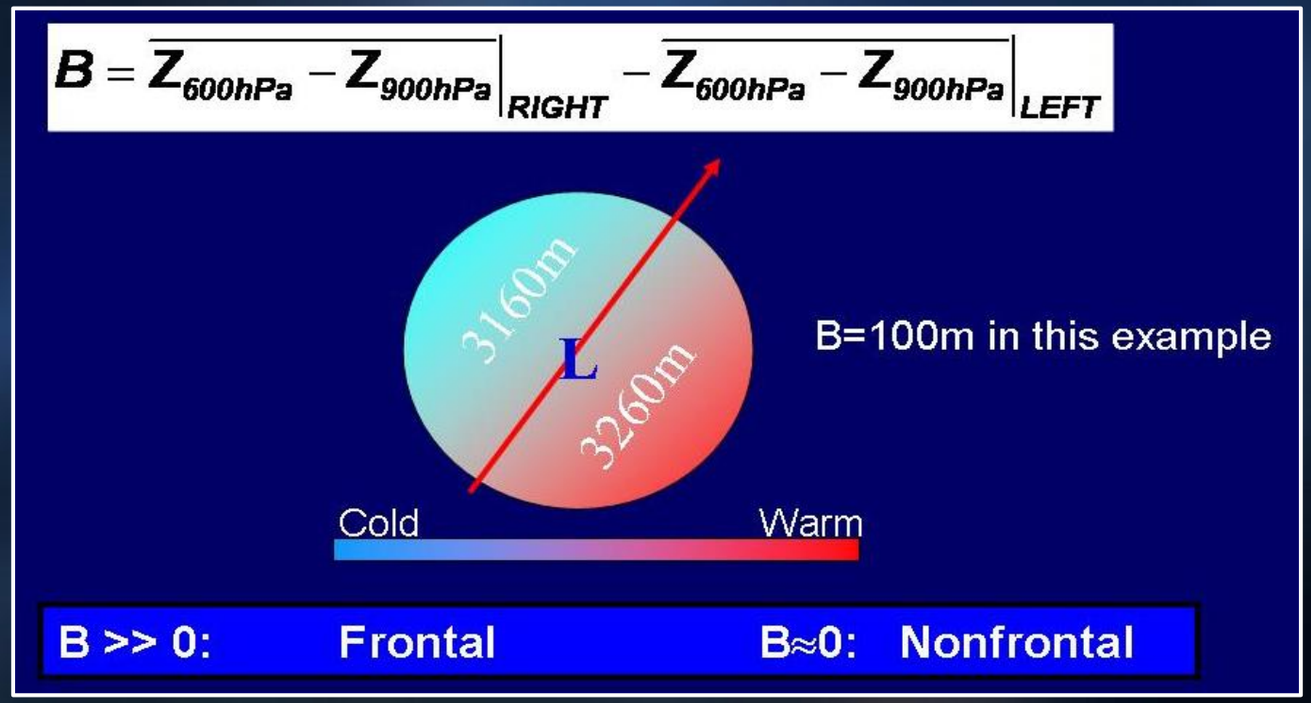


● 台风变性指数

Extra Tropical Transition Index（ETI）

✓ 热力非对称性指数（Thermal Asymmetry）

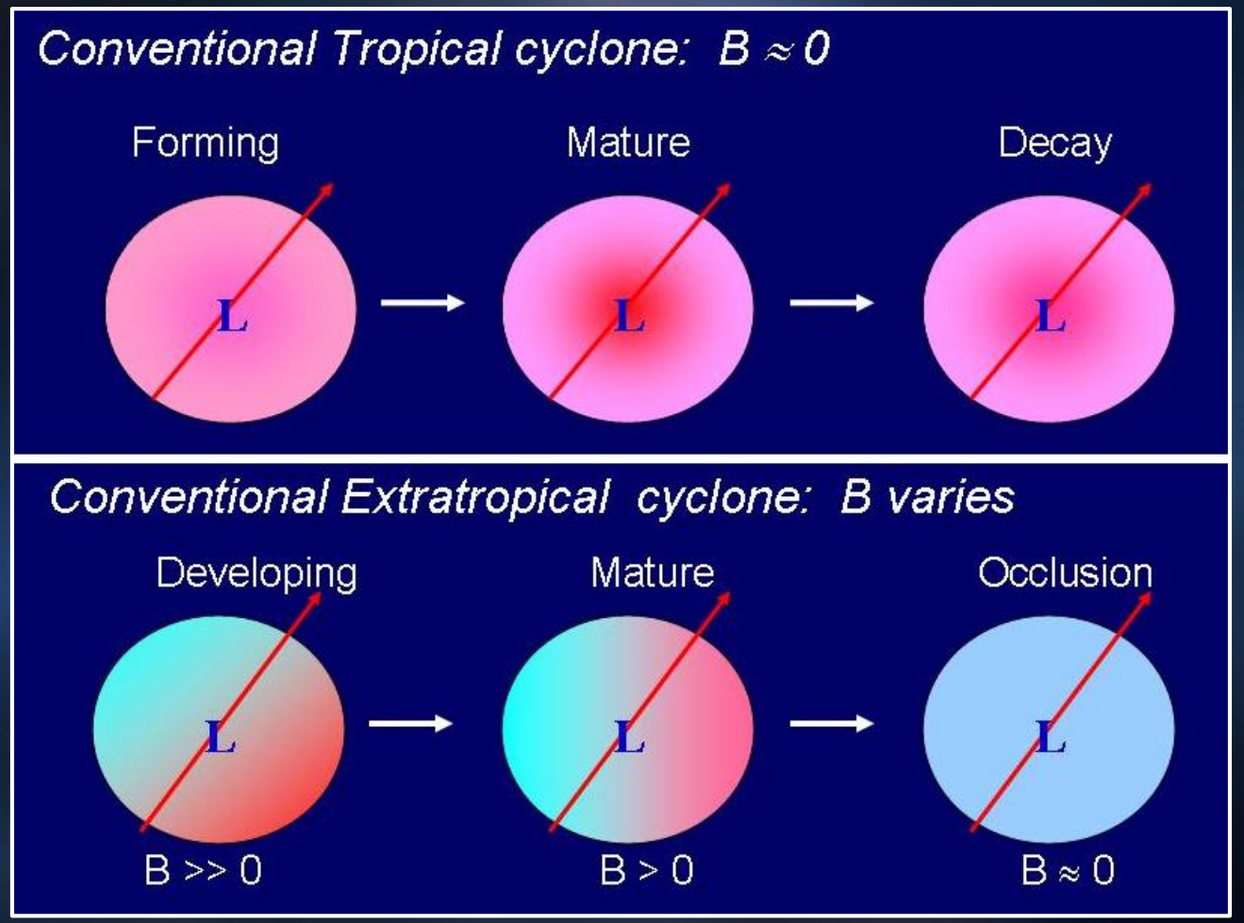
- 按台风移动方向将以台风中心为圆心、半径为500km的圆形区域分为左右半圆，左右半圆600-900hPa的平均等压面高度差的非对称性差异定义为热力非对称性指数B，用公式表示如下：



- **台风变性指数**

  Extra Tropical Transition Index（ETI）

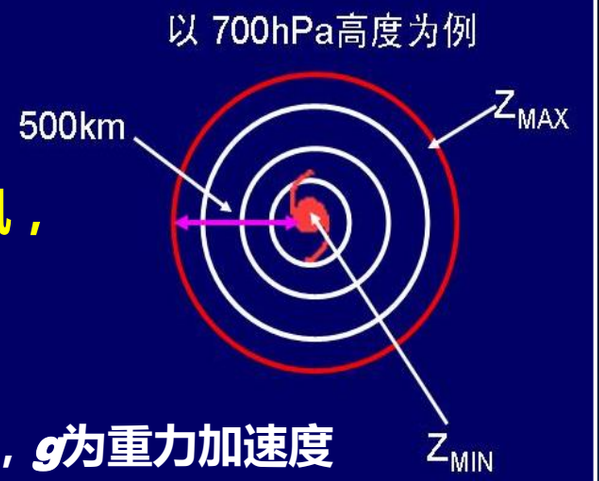
✓ **热力非对称性指数（Thermal Asymmetry）**



✓ 热成风指数（Thermal wind）- V_T

500km半径范围内等压面高度差:

$$\Delta Z = Z_{MAX} - Z_{MIN}$$



中高纬地区，高空风十分接近地转风，由地转风(V_g)平衡关系，得到：

$$\Delta Z = d\, f\, |V_g| / g$$

d **为等压面高度差的距离，** ***f*** **为科氏参数，** ***g*** **为重力加速度**

由热成风(V_T)平衡关系，得到：

$$\left.\frac{\partial(Z_{MAX}-Z_{MIN})}{\partial \ln p}\right|_{900hPa}^{600hPa} = -\left|V_T^L\right|$$

$$\left.\frac{\partial(Z_{MAX}-Z_{MIN})}{\partial \ln p}\right|_{600hPa}^{300hPa} = -\left|V_T^U\right|$$

$-V_T^L < 0$ & $-V_T^U < 0$ → **Cold-core**

$-V_T^L > 0$ & $-V_T^U > 0$ → **Warm-core**

根据静力学公式，台风是暖心结构，气压梯度随高度减少