Tropical Cyclone Formation and Forecasting Technique

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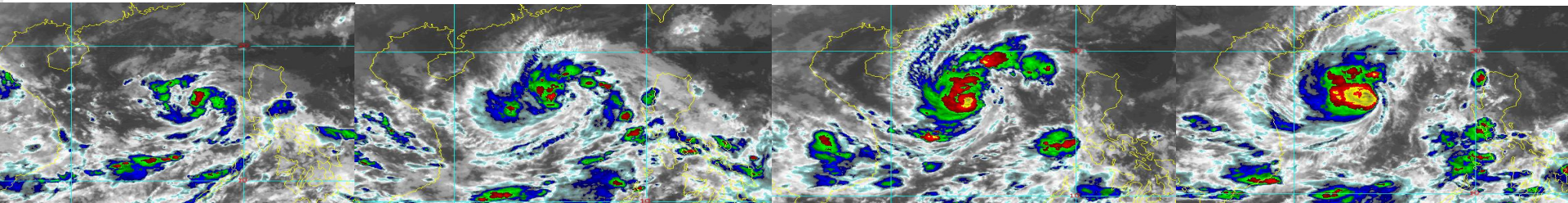
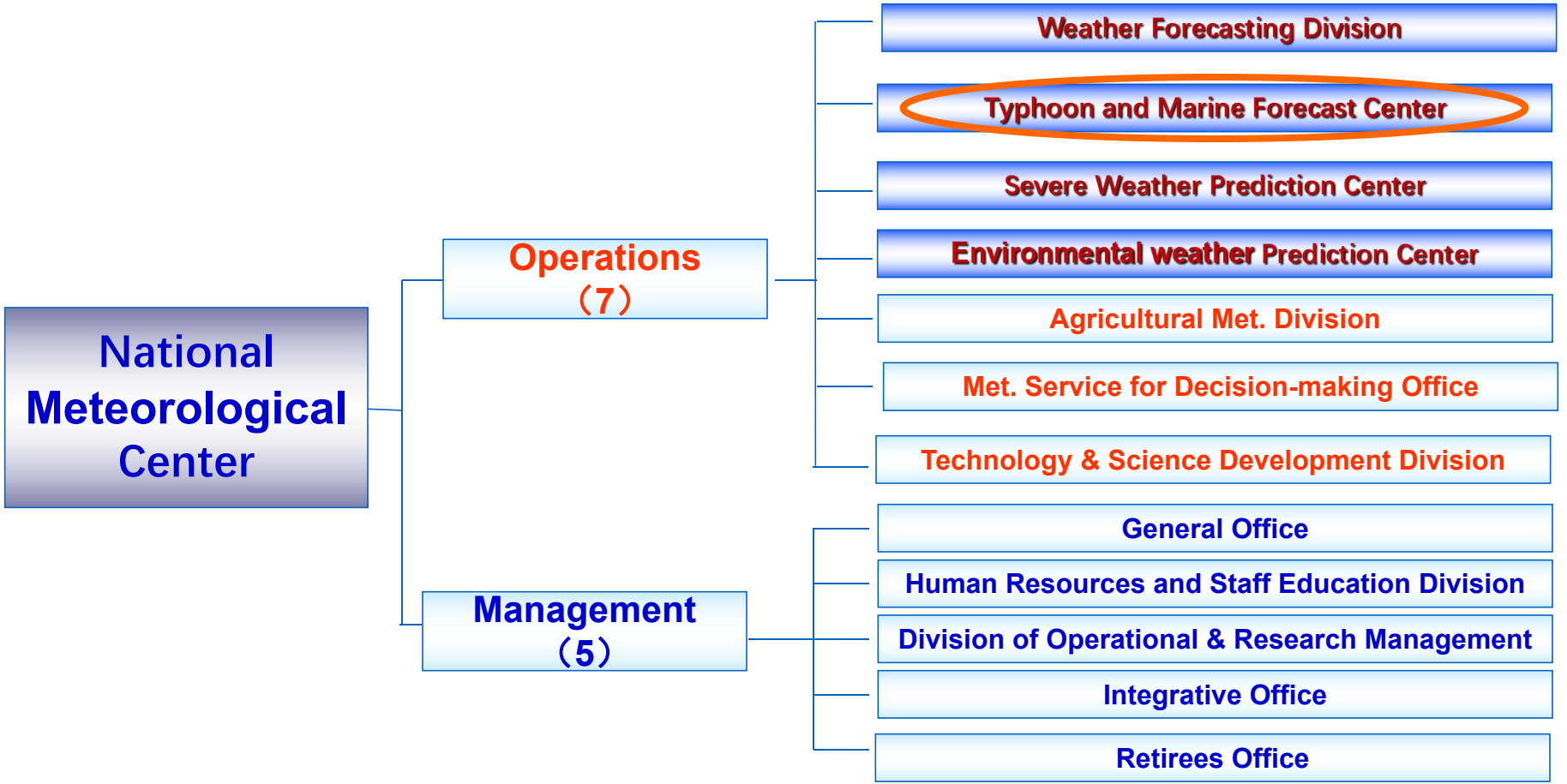
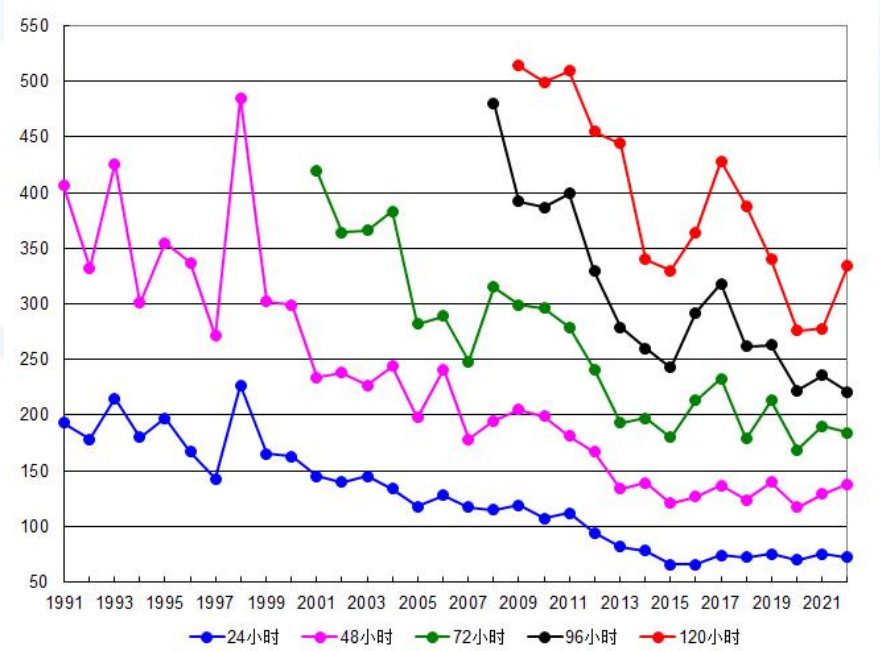


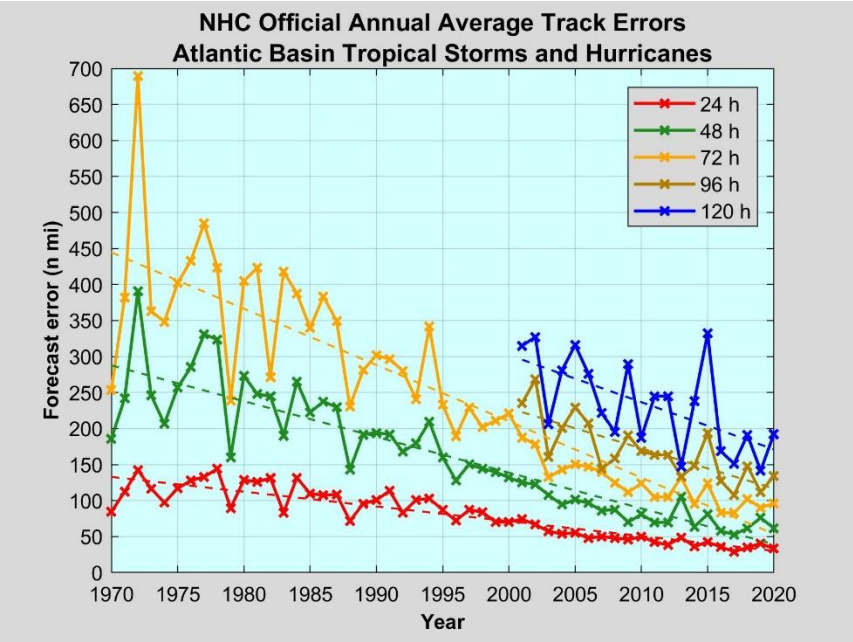
Duty Room of NMC

Brief introductions : Organizational Structure

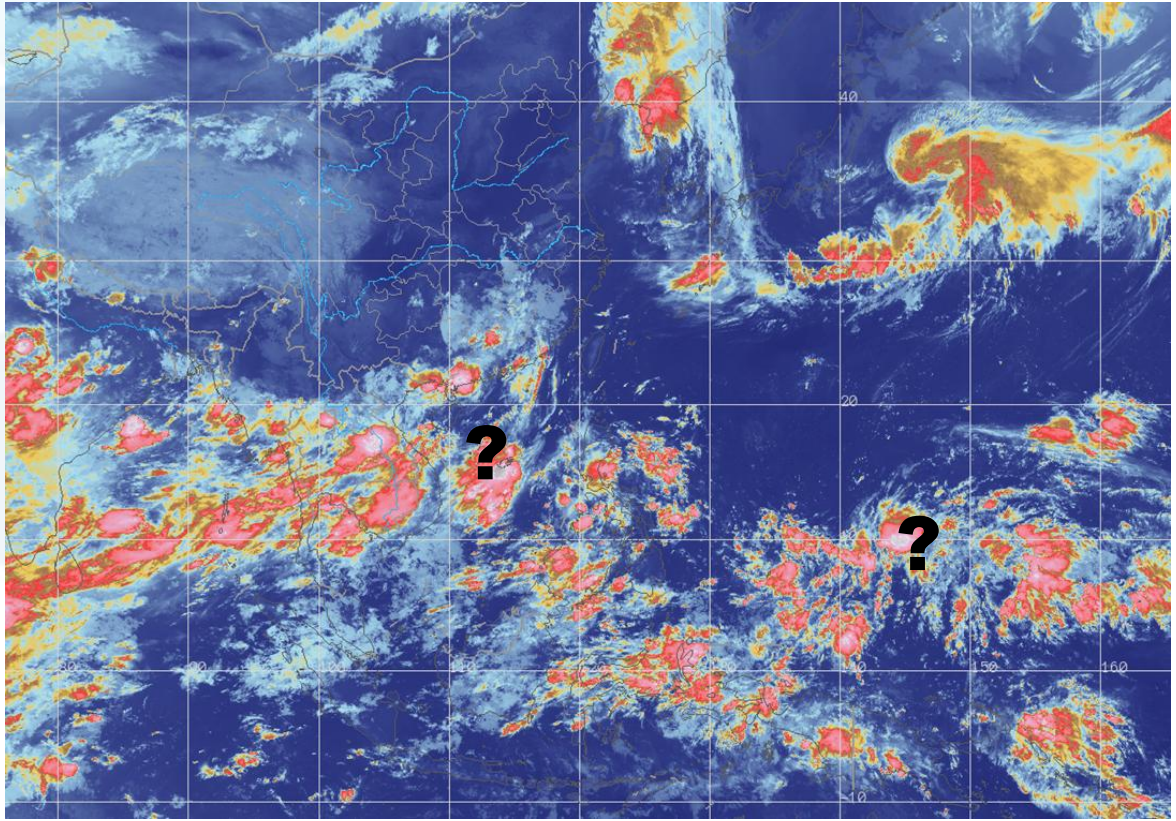


1991-2022 CMA official typhoon track errors





- CMA official typhoon track forecast has make great progress during recent 20years.
- 24h tack error almost decrease to half of 20 years ago.



- When are there TC formation?
- Can the disturbance develop into a named storm?

OUTLINE

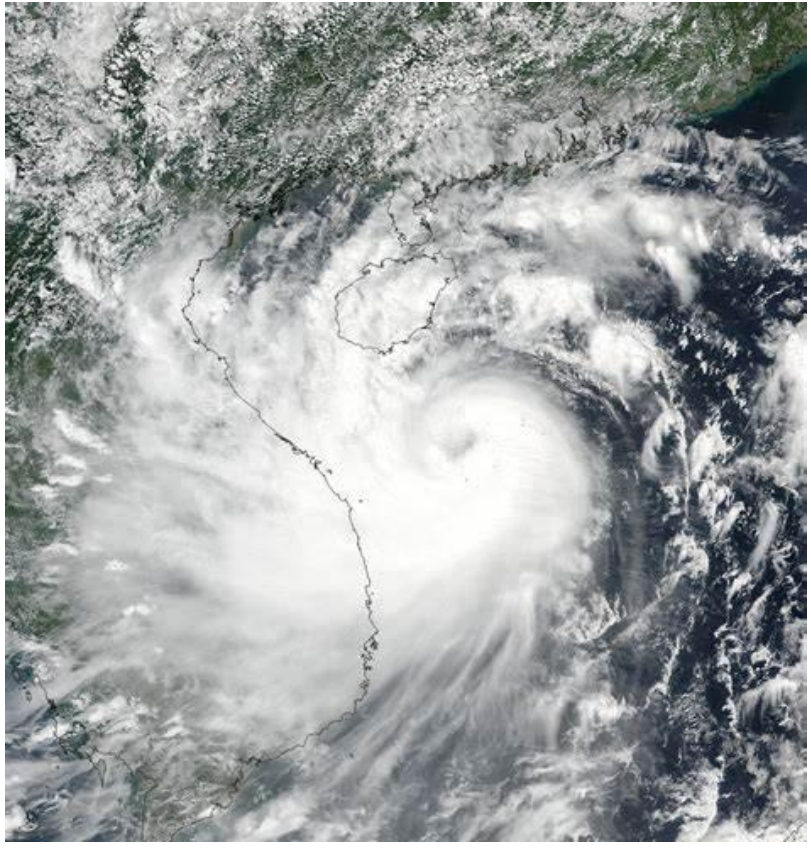
- Climate Background for TC Formation
- Large-scale Conditions Associated with TC Formation
- The Features of MCSs Associated with TC Genesis
- TC Formation Forecasting
- Conclusions and Discussions

The Definition of TC Formation

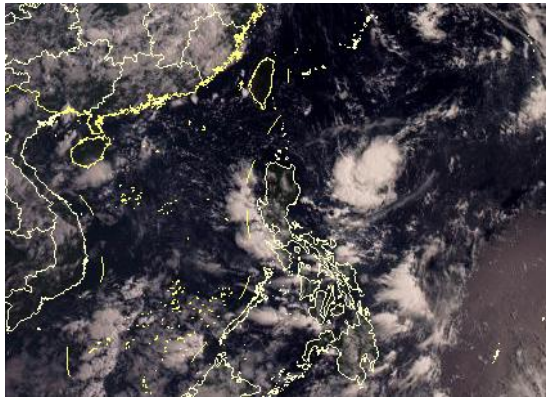
WMO Definition of a Tropical Cyclone:

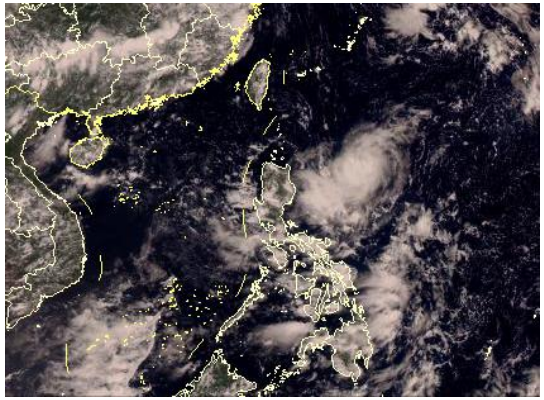
A tropical cyclone is defined as

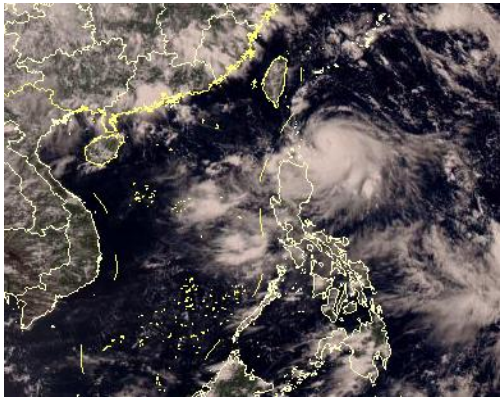
a warm-core, non-frontal synoptic-scale cyclone, originating over tropical or subtropical oceans, with organized deep convection and a closed surface wind circulation about a well-defined center.



The Definition of TC Formation







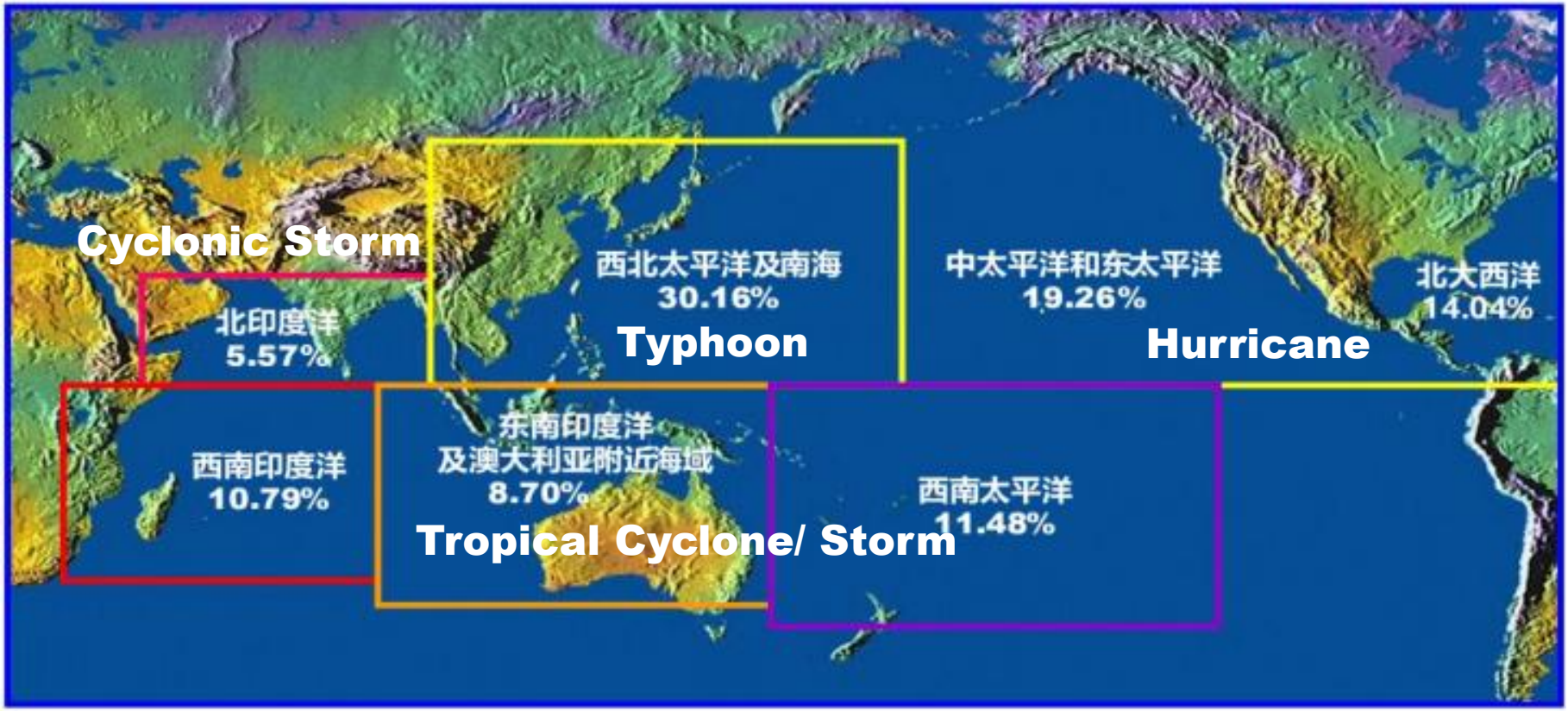
Disturbance **Tropical Depression** **Tropical Storm**

TC Genesis

TC Formation

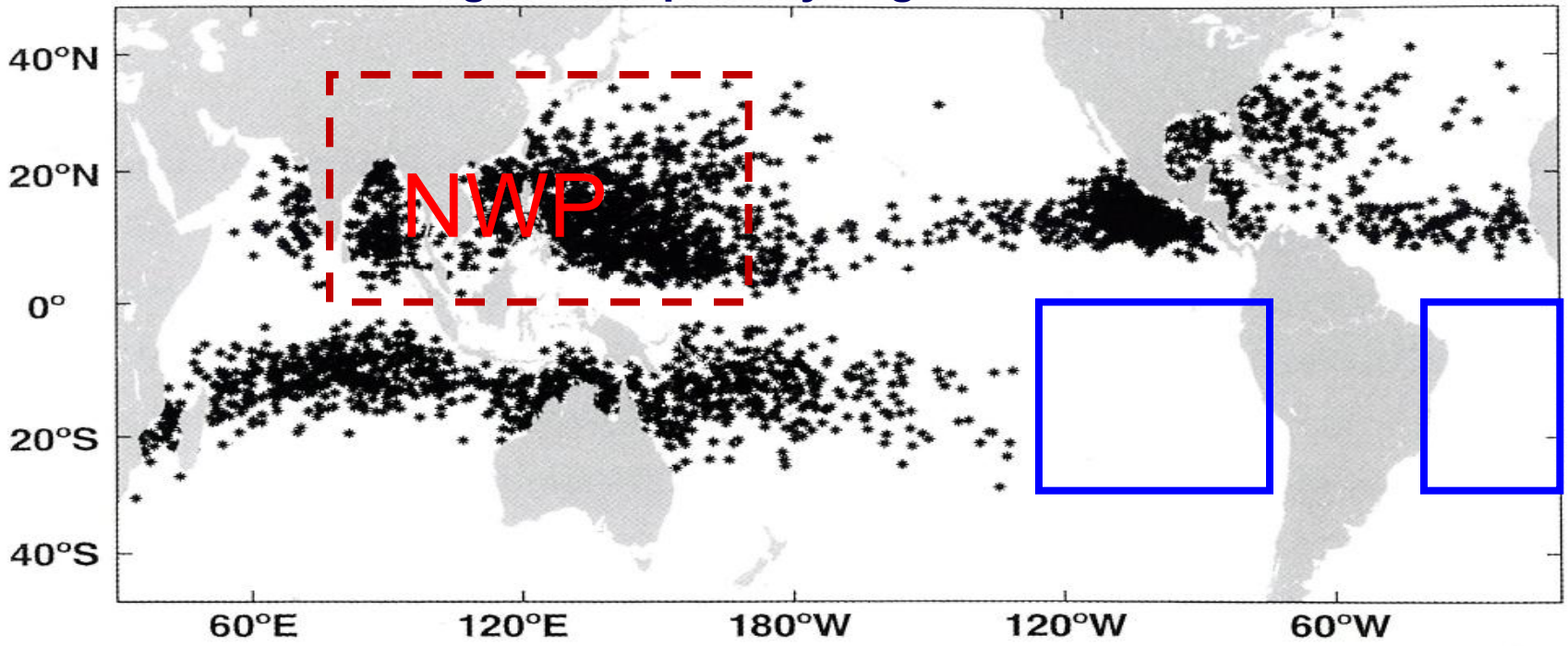
TC Formation is the process that a tropical disturbance develops into a tropical storm (The maximum surface wind≥18m/s).

Brief introductions : Climate Background



Brief introductions : Climate Background

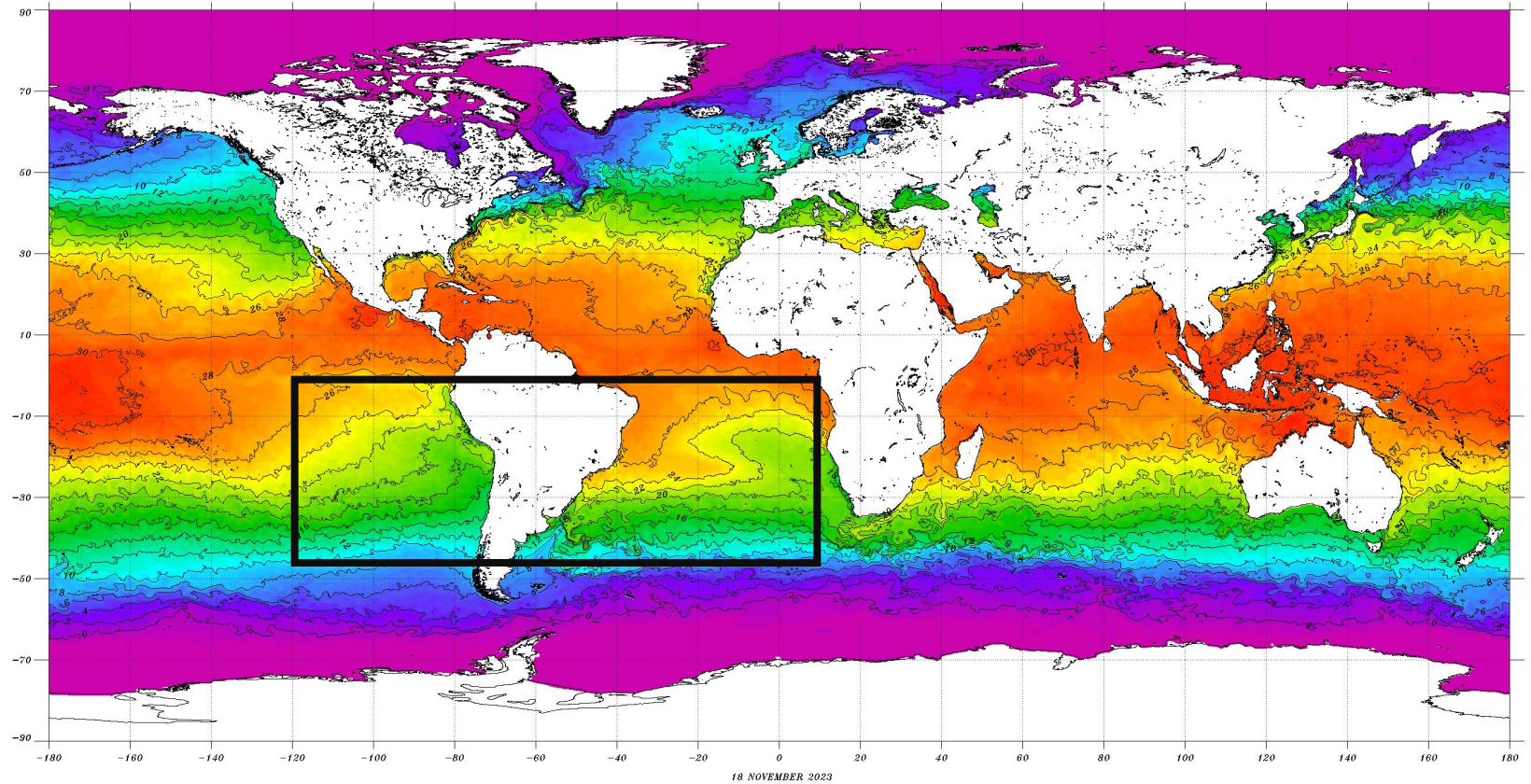
- Northwestern Pacific is the most active basin for tropical cyclones in the world, with about 30% of the global tropical cyclogenesis events.



Tropical cyclone genesis positions in all basins during the past 30 years.

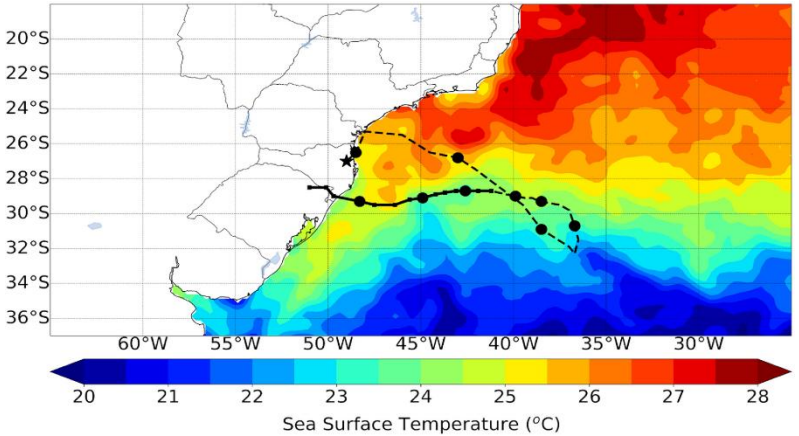
The western South Atlantic Ocean Basin

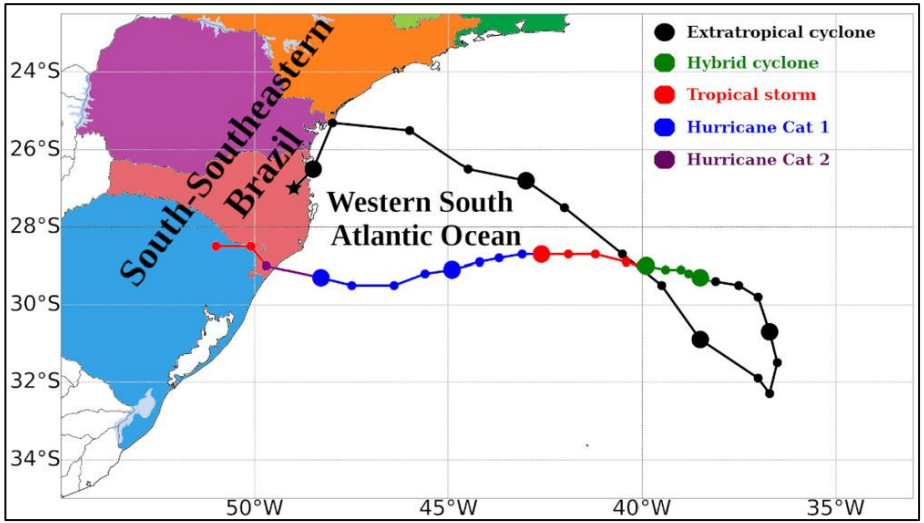
- **Unfavorable conditions: Strong vertical wind shear and cool SST**

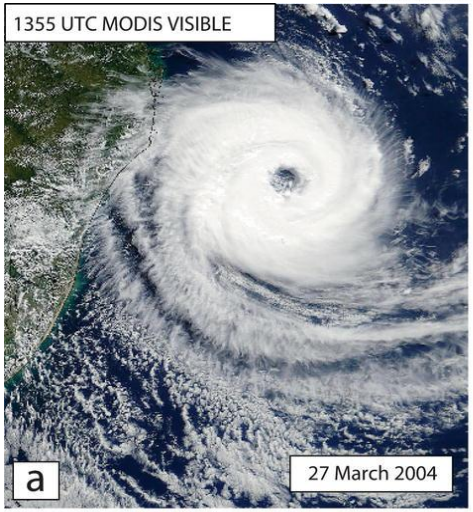


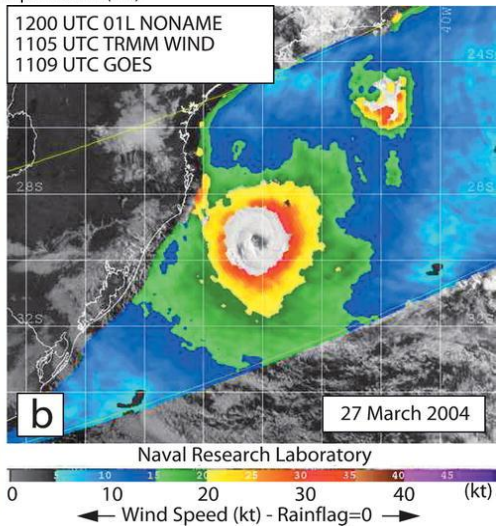
The Rarest Typhoon
Hurricane Catarina (2004) over the western South Atlantic Ocean

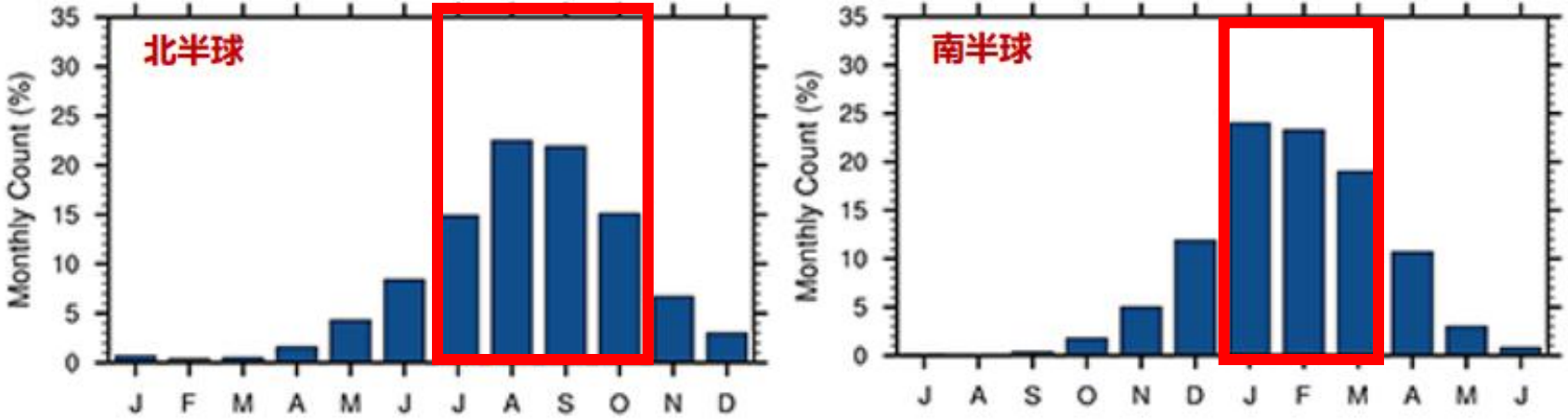
- Beginning as an extratropical precursor
- Catarina begins a tropical transition process over anomalously cool 25 ^{o}C ocean waters
- Structures: warm core, clear eye, spiral cloud bands
- The first south Atlantic hurricane







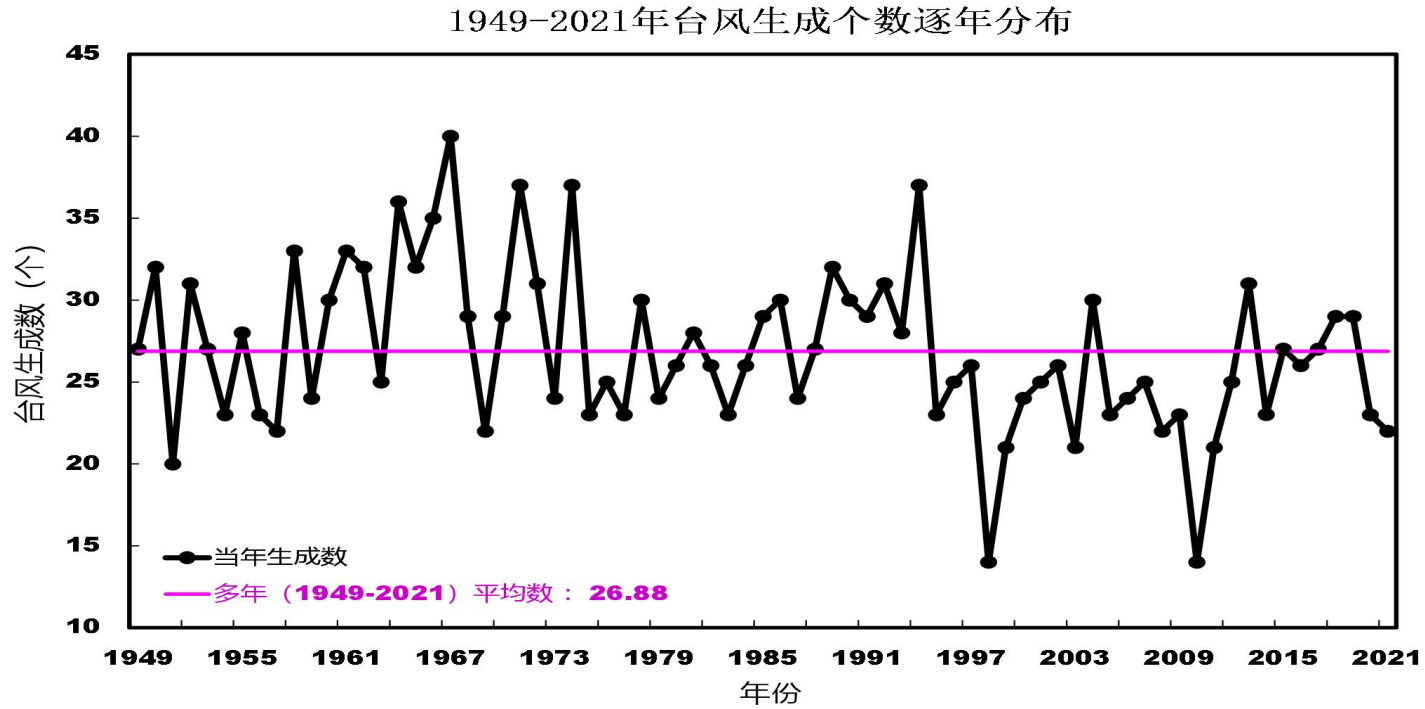




The monthly TC formation frequency in the Northern Hemisphere and the Southern Hemisphere.

- In the Northern Hemisphere, the tropical cyclone seasons typically extend from May through December. The active season is in July to October.
- In the Southern Hemisphere, the tropical cyclone seasons typically extend from November through April. The active season is in January to March

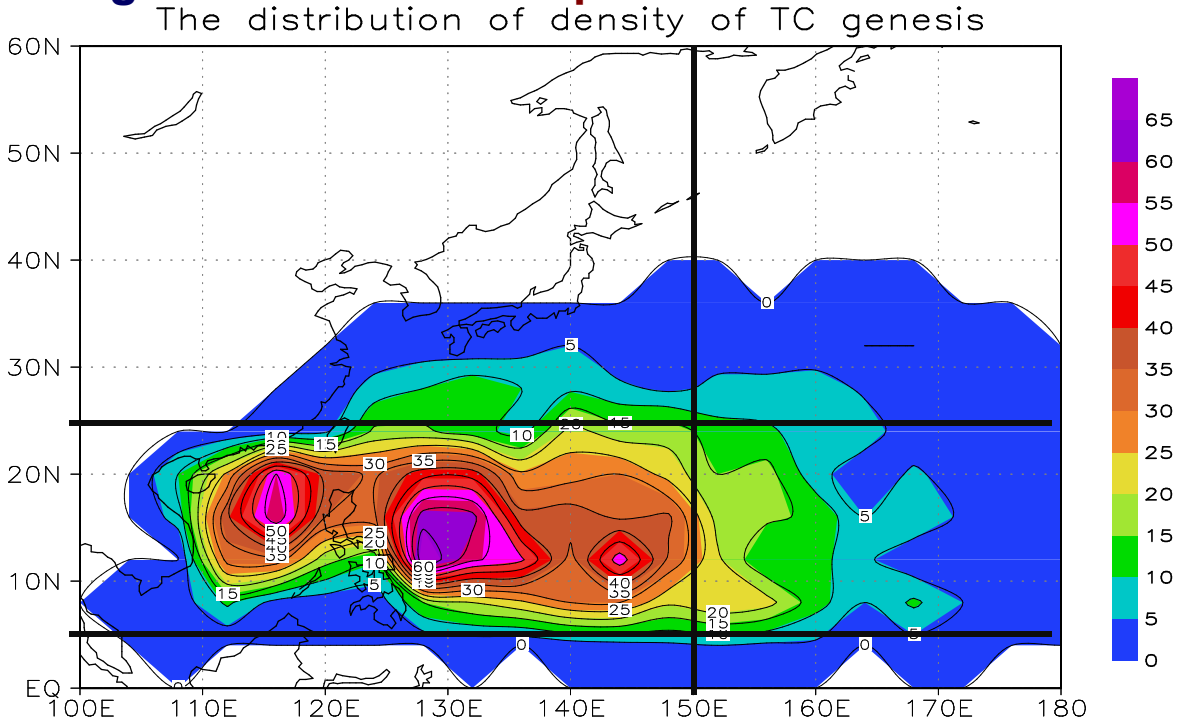
- **Generally, there are 27 TCs generated each year.**
- **The maximum number of TC formation is 40 in 1967.**
- **The minimum number of TC formation is 14 in 1998 and 2010.**



The annual number of TC formation frequency in NWP basin from 1949 to 2021

Brief introductions : Climate Background

- Most TC genesis in Northern part of SCS and sea east of Philippines.

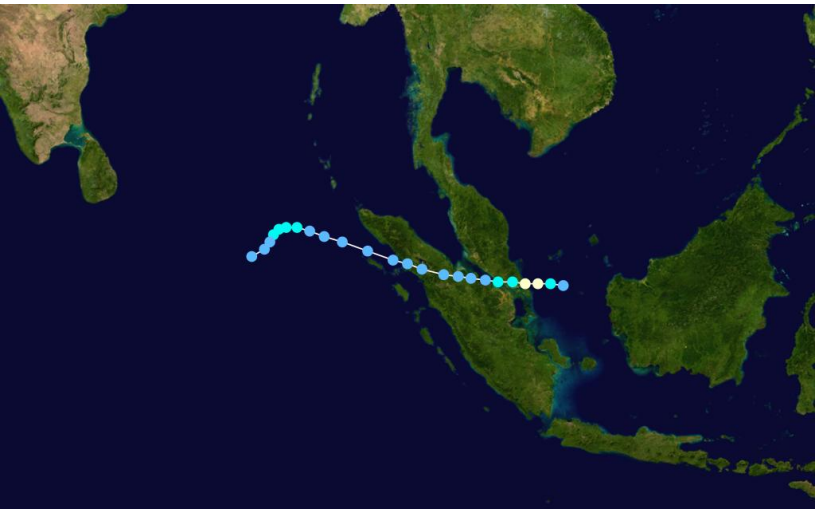


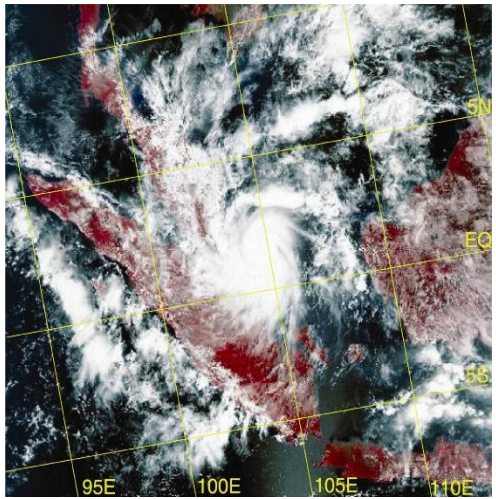
Density distribution of of TC genesis over the Northwest Pacific and the South China Sea from1949 to 2020 (isoline,units: incident·π-1R-2, R=250 km)

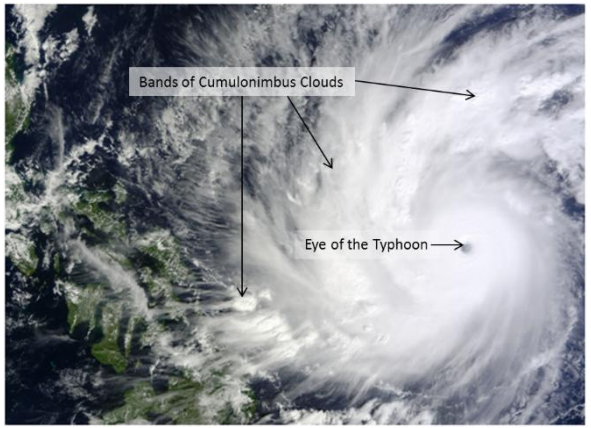
The Rarest Typhoon

Typhoon Vamei (2001) Formed over equator near Singapore

- Typhoon Vamei formed very close to the equator (1.5 ^{o}N) on December 27, 2001.
- No TC in recorded history had formed within 200 miles of the equator before 2001.
- Typhoon Vamei is the first cyclone that made landfall in Singapore.



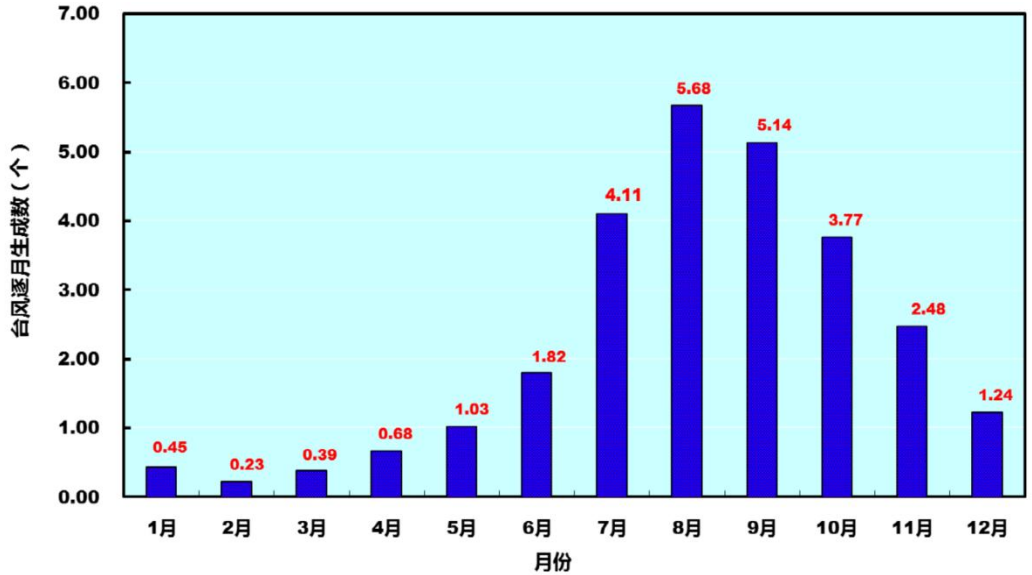




http://www.weather.gov.sg/learn_phenomena/

Brief introductions : Climate Background

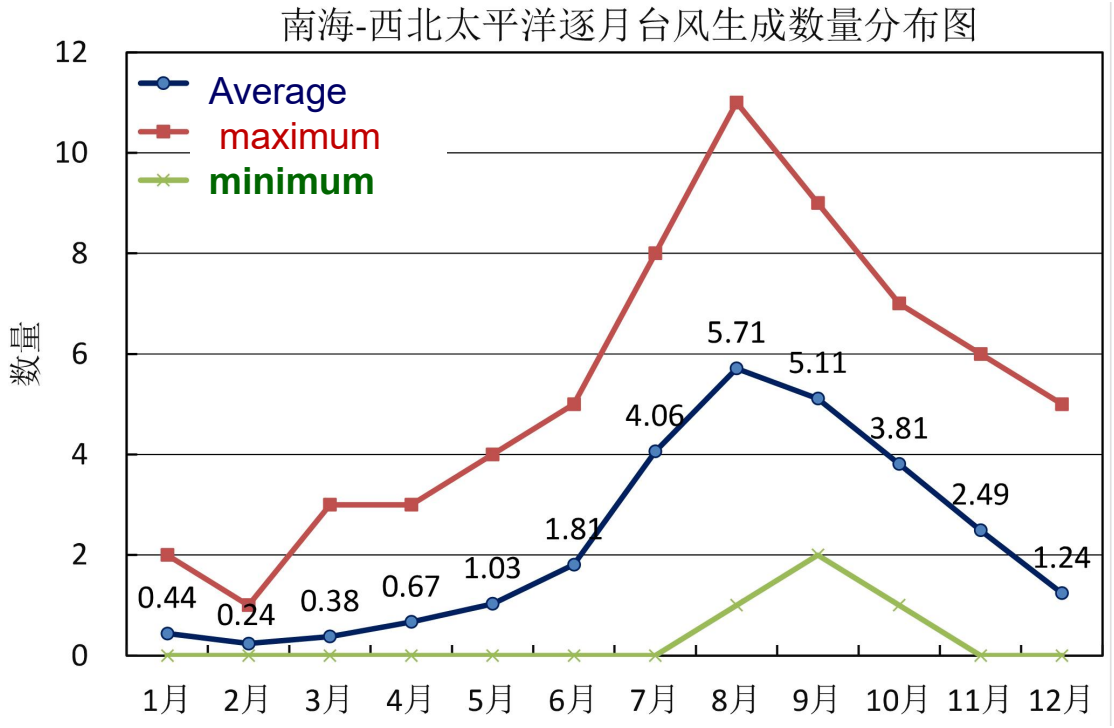
- The TC active months are in July, August and September, with a peak in August. About 56% of TC genesis occur mainly in July, August, and September.
- Very few TC genesis occur in January, February, and March.



The monthly TC formation frequency of 1949-2018 over the Northwest Pacific

Brief introductions : Climate Background

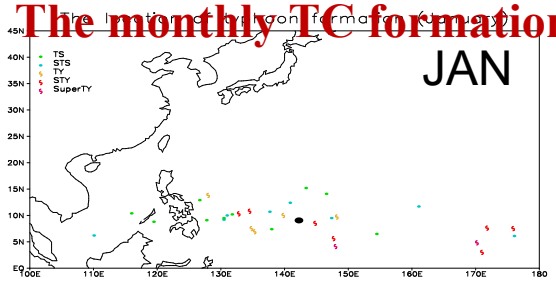
- **The number of TC formation varies greatly every month.**

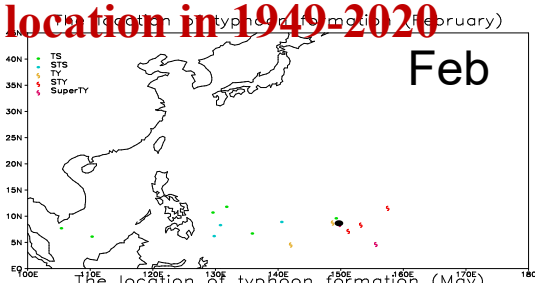


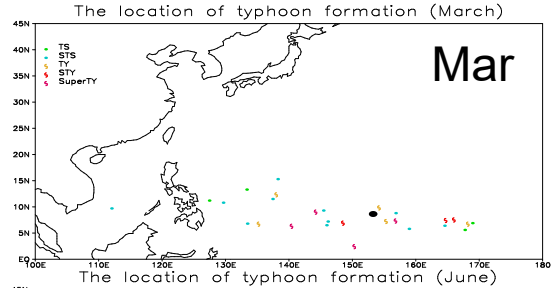
- ✓ No TC formation in July 2020, and first no TC in July
- ✓ Only one TC moved from EP basin into NWP, no TC formation in NWP

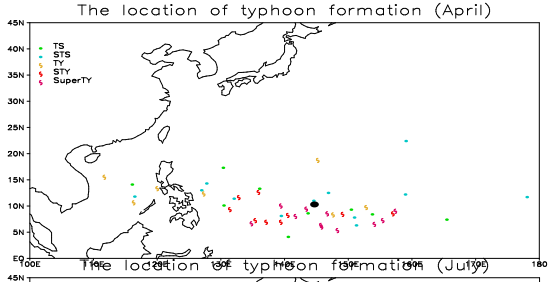
The monthly TC formation frequency of 1949-2018 over the Northwest Pacific

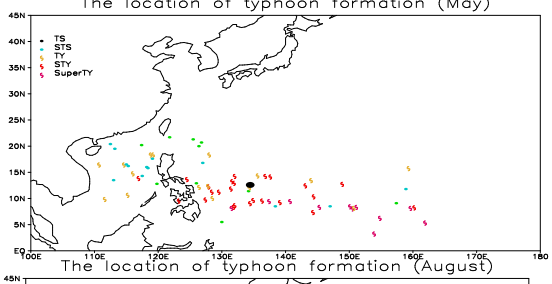
The monthly TC formation location in 1949-2020

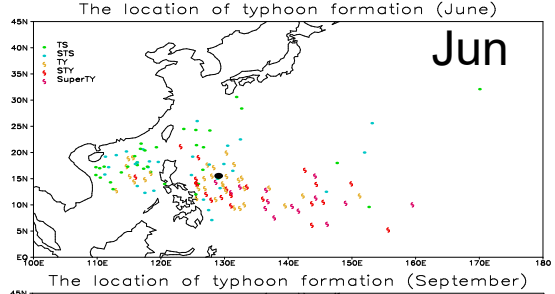


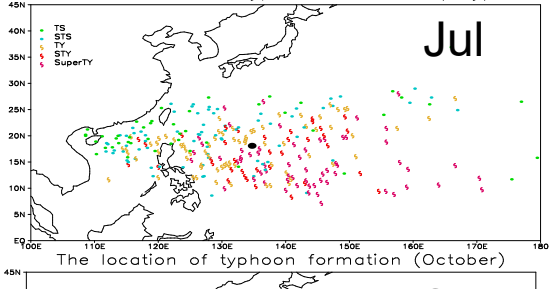


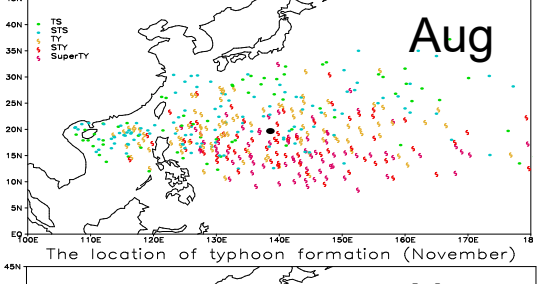


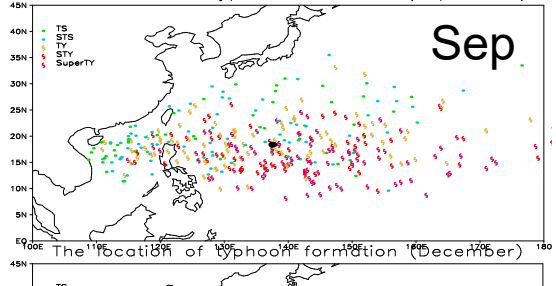


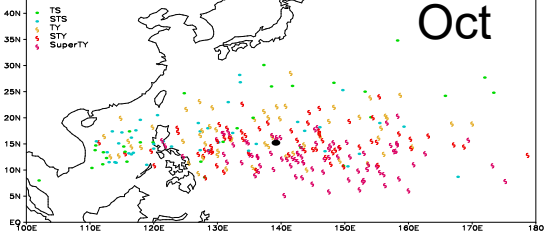


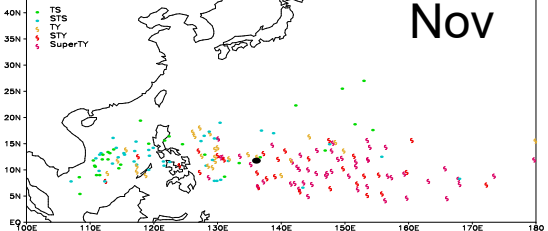


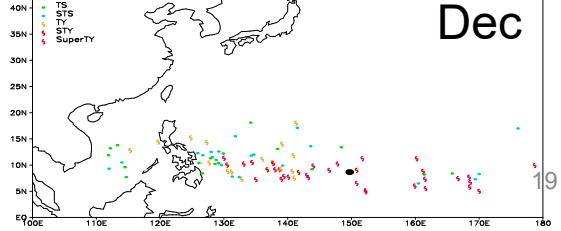




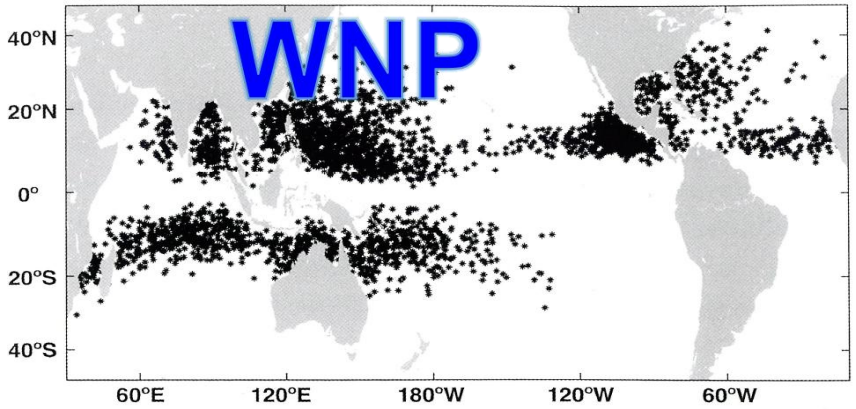


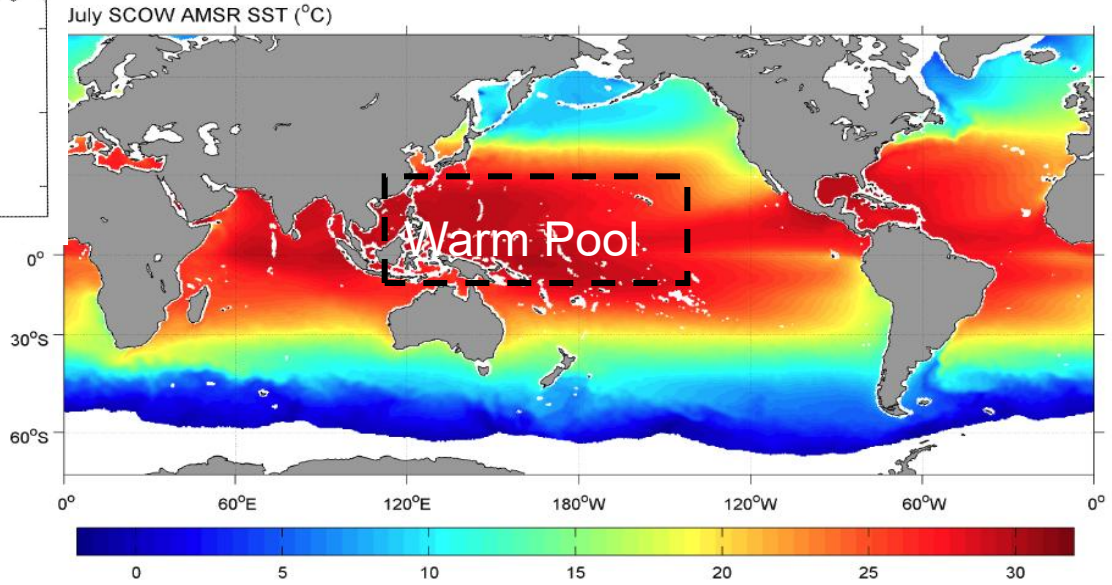






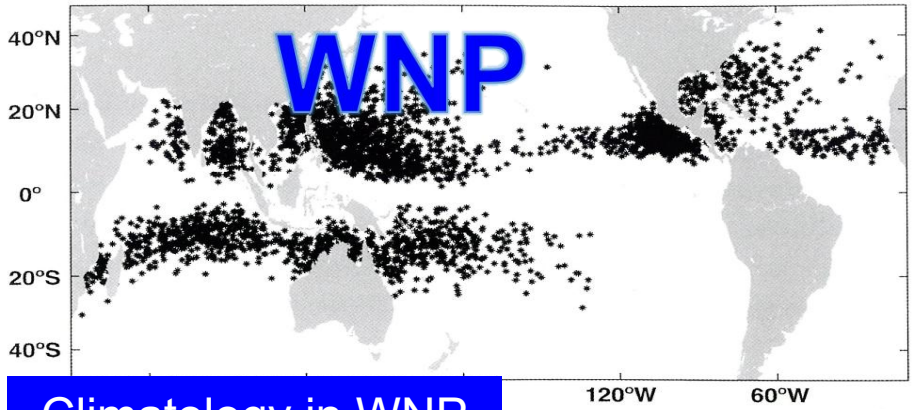
Why TC genesis in WNP is so active?





- The TC genesis frequency is higher in the warm pool area.
- Warm pool can provide more potential energy for TC genesis.

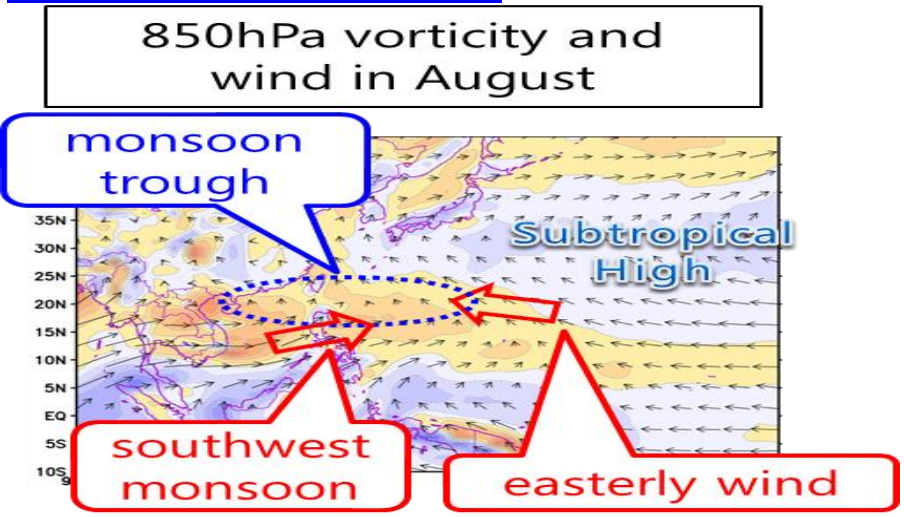
Why TC genesis in WNP is so active?

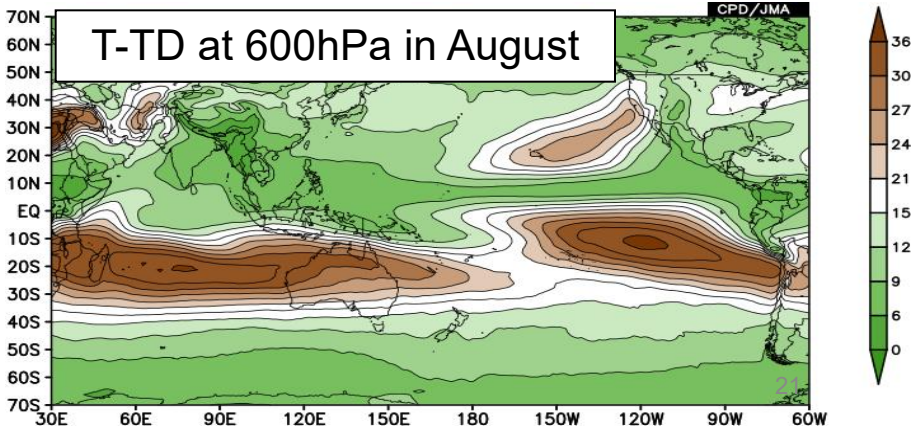


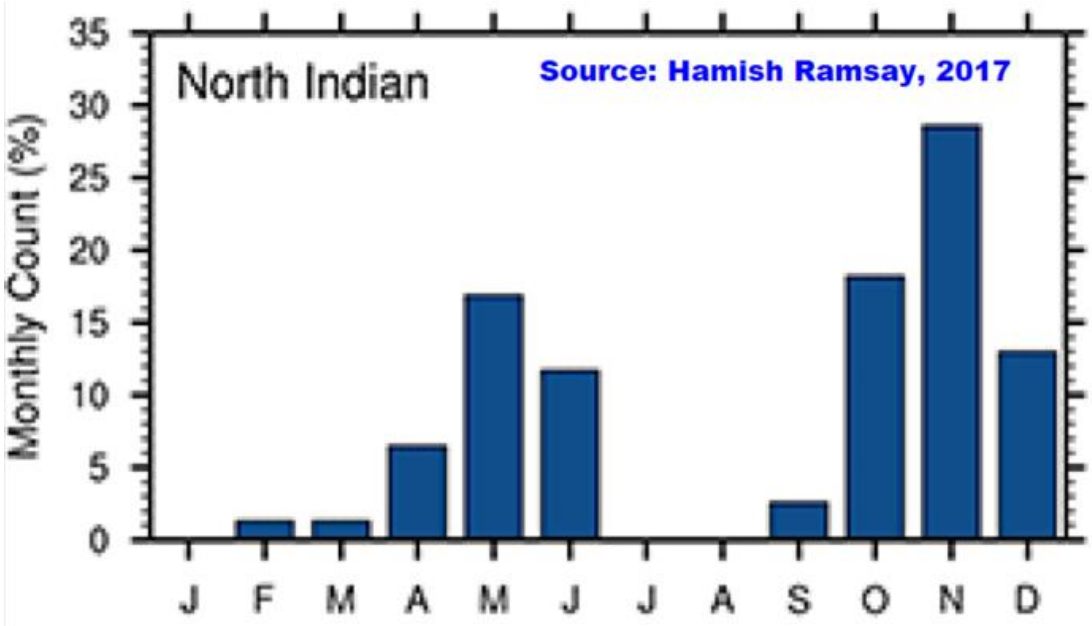
Climatology in WNP

Necessary Conditions for TC Formation:

(i) Abundant ocean thermal energy [SST > 26° C tovextending a depth of 60 m],
(ii) Enhanced mid-troposphere (600-700 hPa) relative humidity,
(iii) Conditional instability (normally met) in the tropical region),
(iv) Enhanced relative vorticity in the lower troposphere,
(v) Weak or small vertical shear of the horizontal winds at the genesis site, and
(vi) Latitude poleward of ~5°



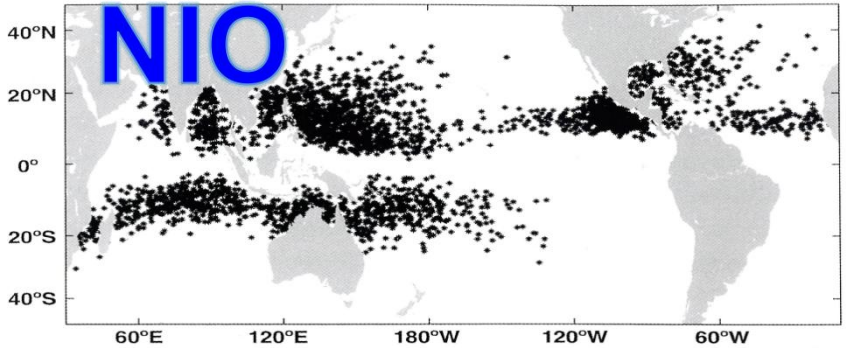




The monthly TC formation frequency over the North Indian.
（Hamish Ramsay, 2017）

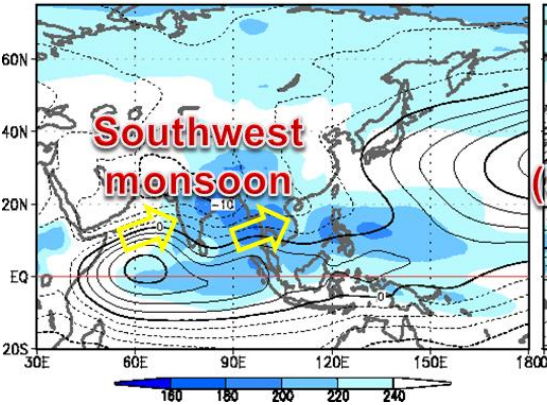
- **North Indian has 14 named storms for one year.**
- **The North Indian has two cyclone seasons, One peak is from April through June and the second from September through December. Between these two peaks, there is little tropical cyclone development.**

Why does no TC form in summer in North Indian Ocean?



Climatological 850hPa circulation in August

01Aug. – 30Aug.



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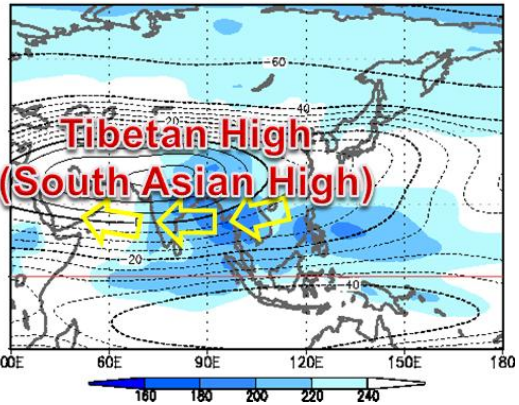


Necessary Conditions for TC Formation:

(i) abundant ocean thermal energy [SST > 26° C extending to a depth of 60 m],

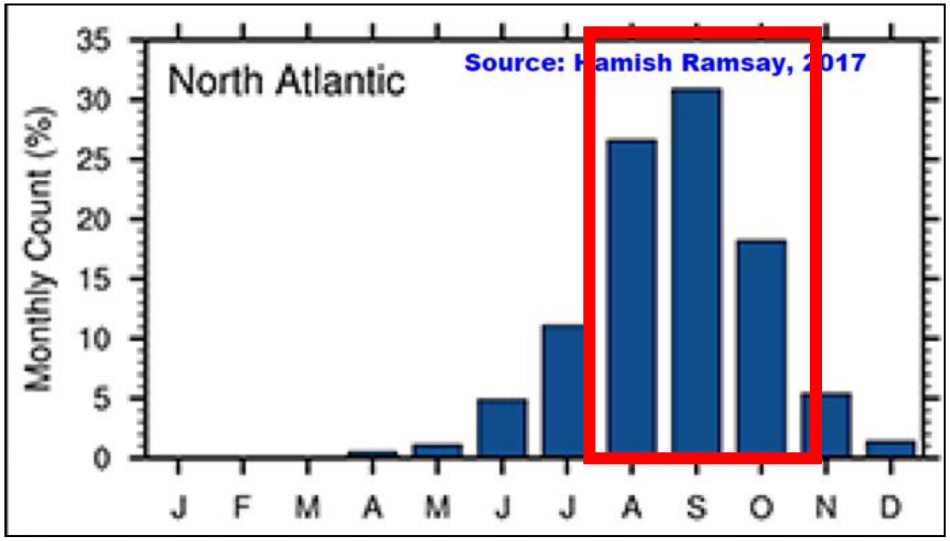
(ii) enhanced mid-troposphere (600-700 hPa) relative humidity,

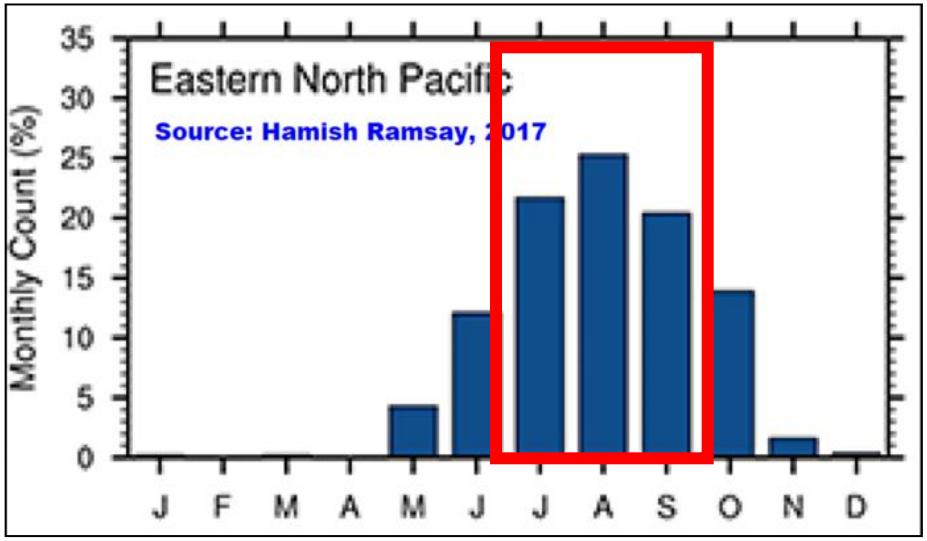
(iii) conditional instability (normally met in the tropical region),

(iv) enhanced relative vorticity in the lower troposphere,

(v) ~~weak vertical shear of the horizontal winds at the genesis site,~~ and

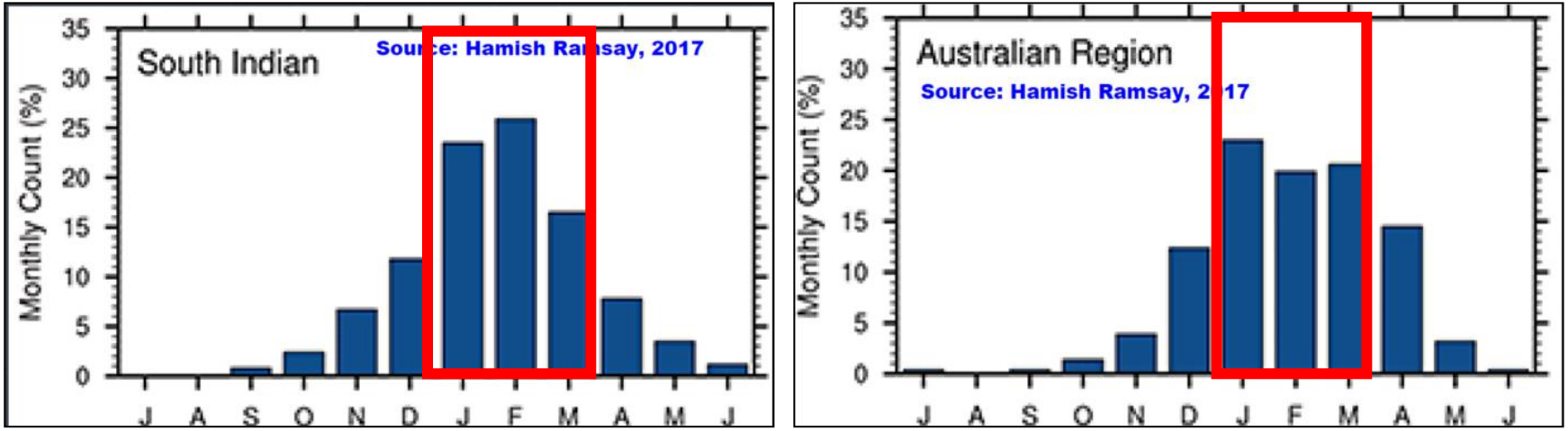
(vi) Latitude poleward of ~5° .





The monthly TC formation frequency over the North Atlantic and Eastern North Pacific. （Hamish Ramsay, 2017）

- **The Atlantic hurricane season runs from June 1 to November 30. On average Atlantic hurricane season has 14 named storms. The peak occurs in September and the first named storm typically forms in mid to late June.**
- **The eastern Pacific hurricane season runs from May 15 to November 30. On average，this basin has 15 named storms. The peak occurs in August and the first named storm typically forms in early to mid-June.**

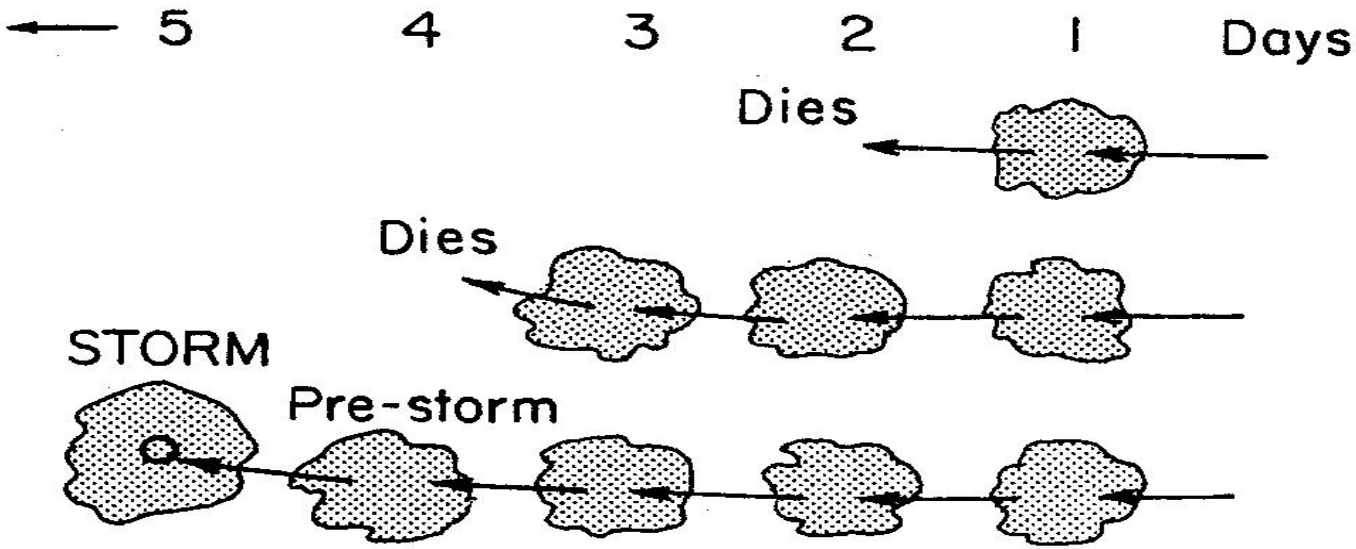


The monthly TC formation frequency over South Indian and Australian region. （Hamish Ramsay, 2017）

- **South Indian and Australian storm season runs from September to June of the next year. On average. The peak occurs in February and the active season is January to March.**

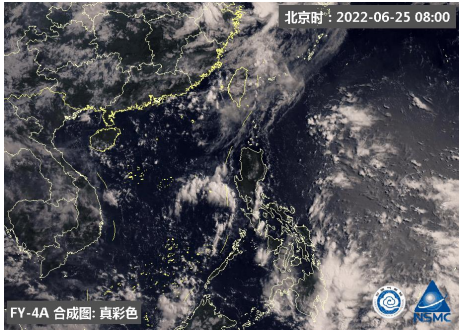
OUTLINE

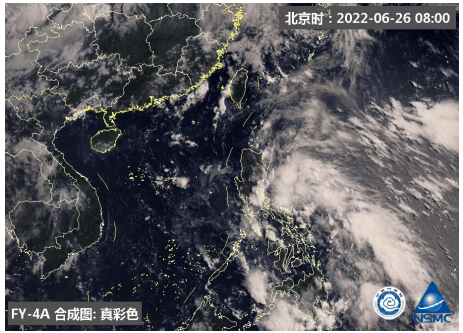
- Climate Background
- Large-scale Conditions Associated with TC Genesis
- The Features of MCSs associated with TC Genesis
- TC Genesis Forecast
- Conclusions

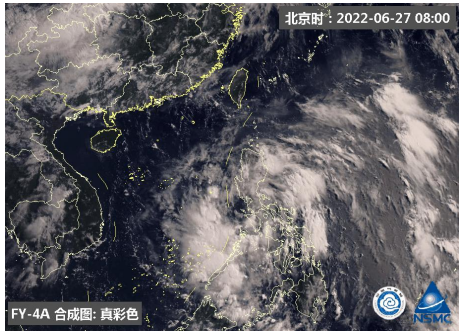


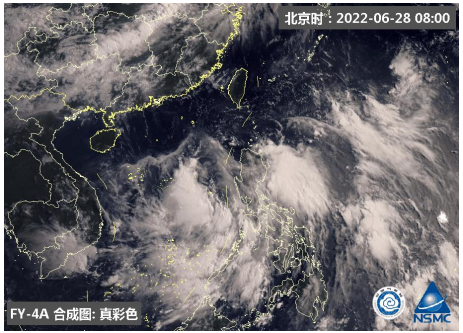
Gray(1998)

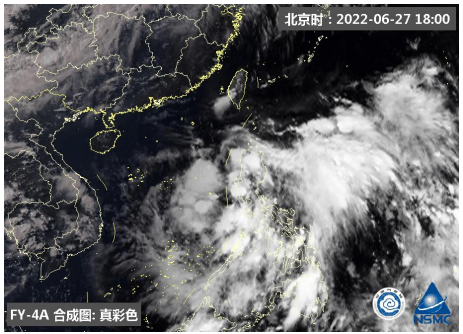
Develop Disturbance

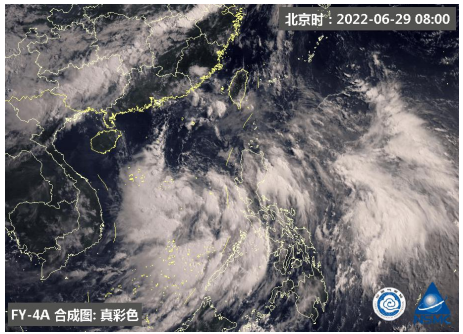


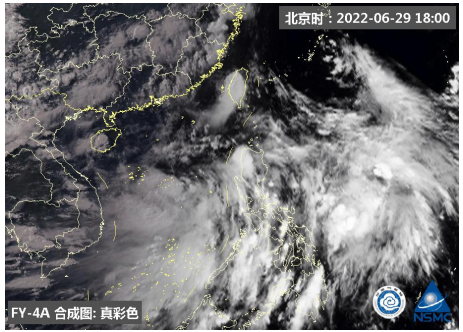


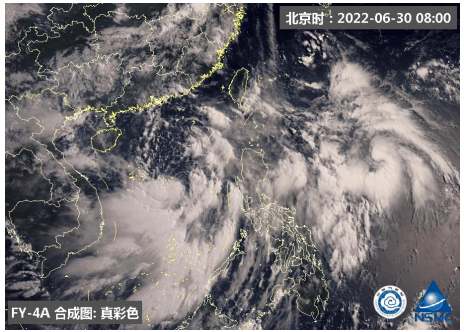






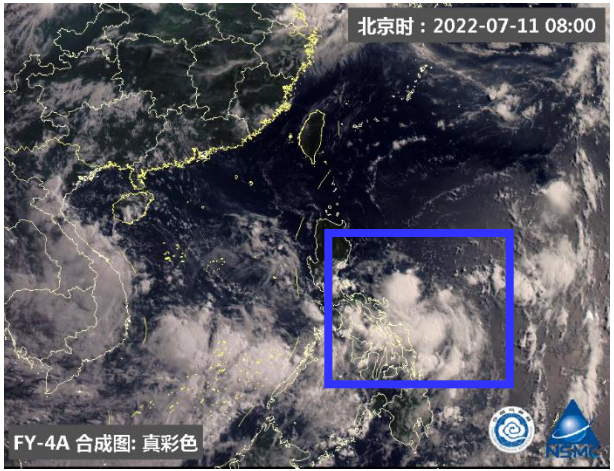


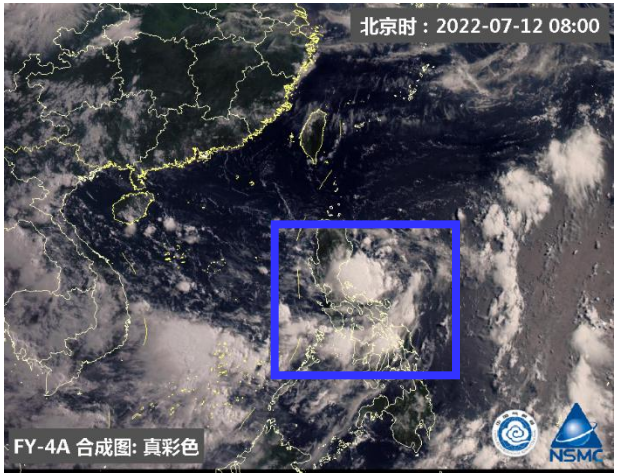


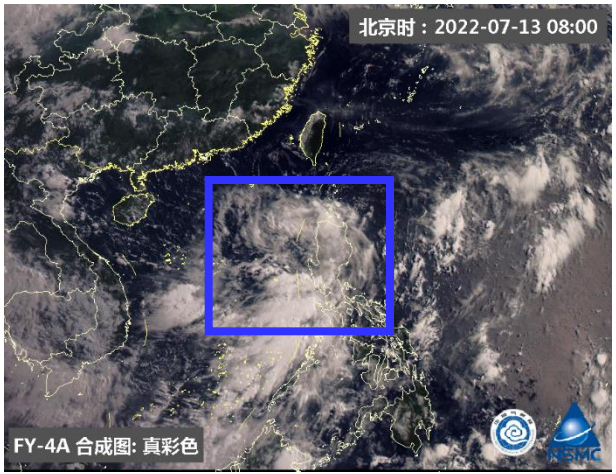


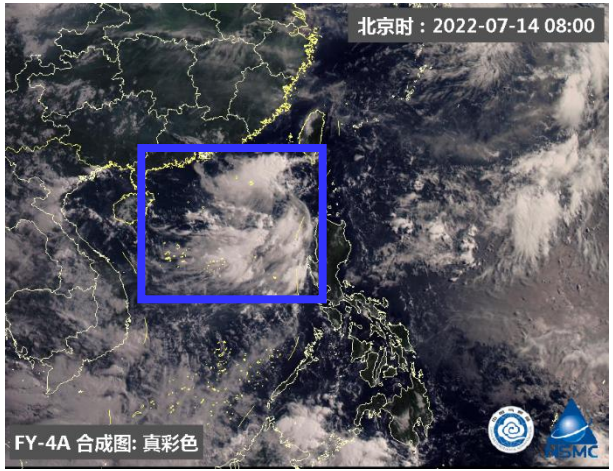
The disturbance from occurrence into a tropical storm using 5 days.

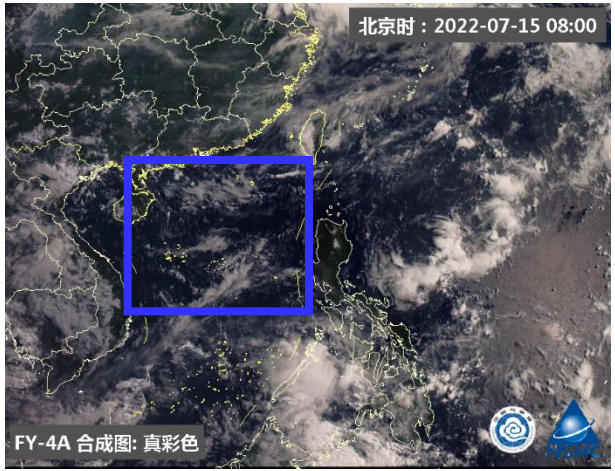
Non-develop Disturbance











Synoptic patterns of TC genesis

Six large-scale patterns (Ritchie and Holland, 1999) :

ITCZ

(1) Monsoon shear line (42%)

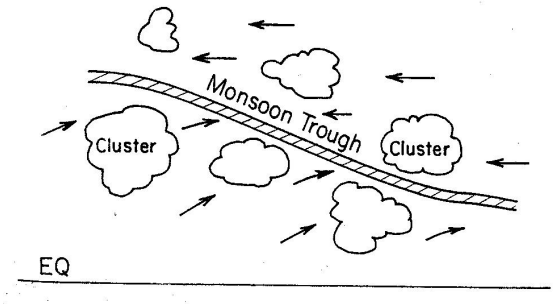
(2) Monsoon confluence region (29%)

(3) Monsoon gyre (3%)

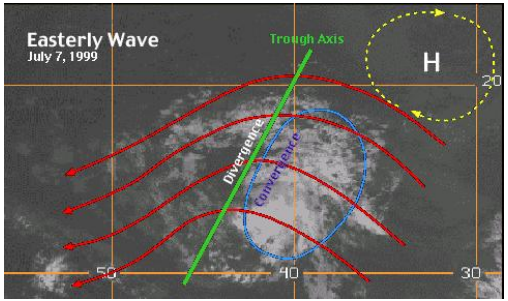
(4) Easterly waves (18%)

(5)Rossby wave Energy dispersion from a preexisting TC (8%)

(6) upper tropospheric trough (TUTT)

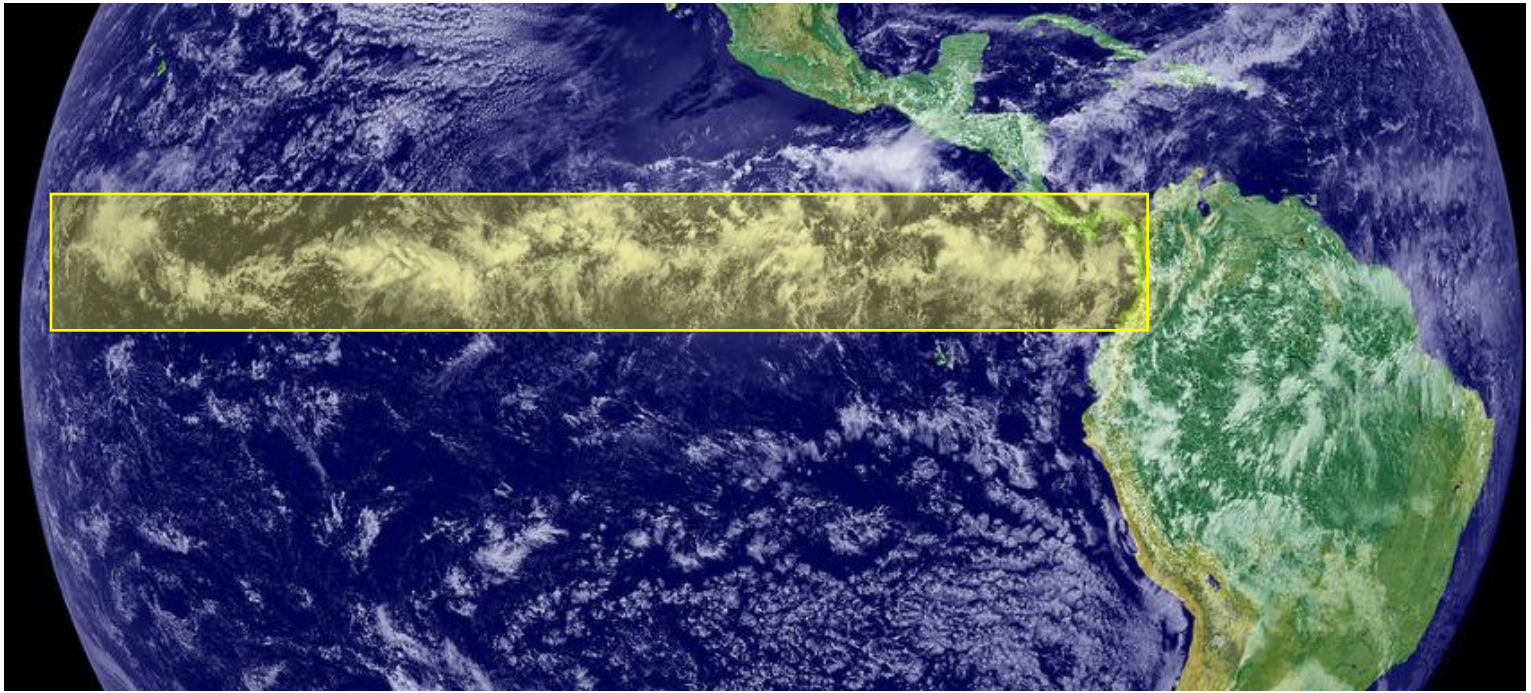


Monsoon shear line



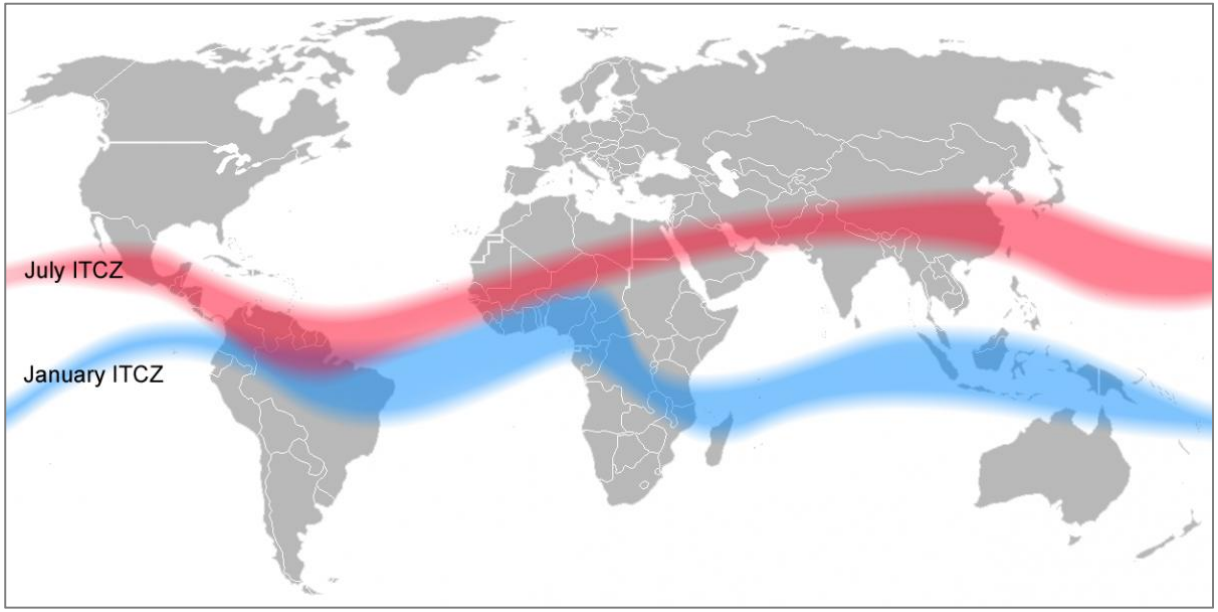
Easterly wave

Intertropical Convergence Zone (ITCZ)



- ITCZ is the region where the northeasterly and southeasterly trade winds converge. It is also a belt of low pressure which circles the Earth generally near the equator.
- It is characterized by convective activity which generates often vigorous thunderstorms over large area.

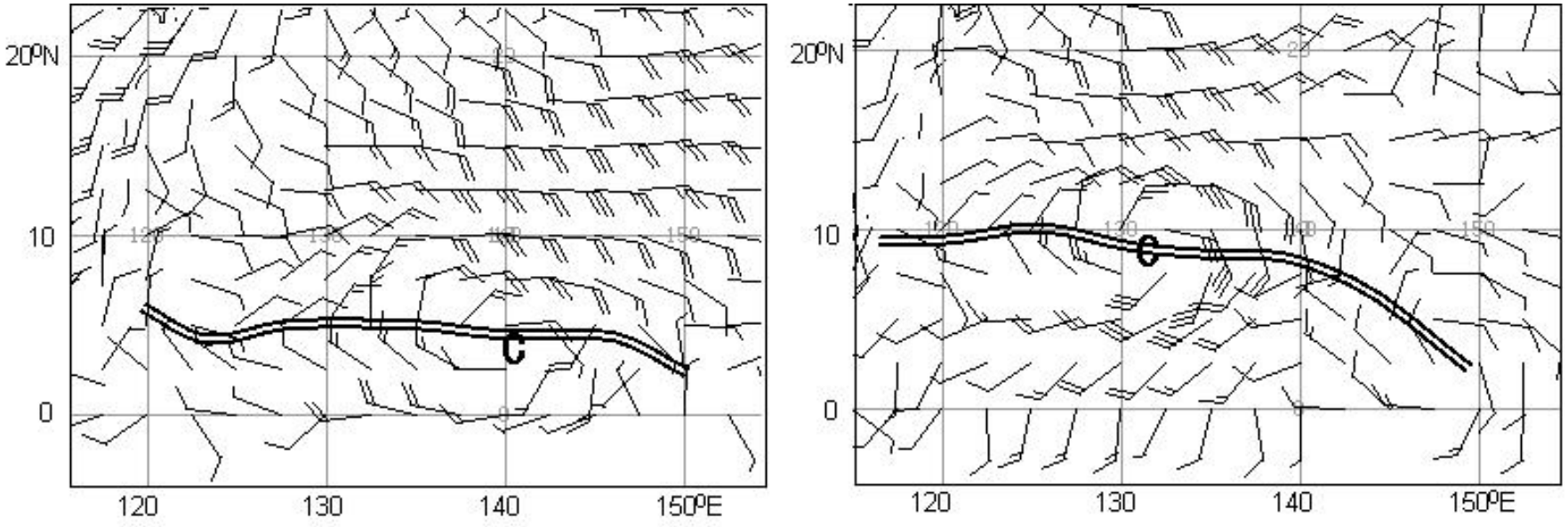
Intertropical Convergence Zone (ITCZ)



Position of the intertropical convergence zone in January (in blue) and in July (in red).
Source: Wikicommons. Author Mats Halldin, 13 Dec 2006.

- **The position of the ITCZ varies with the seasons, and TC formation location move with ITCZ.**
- **About 80% TC form in the ITCZ.**

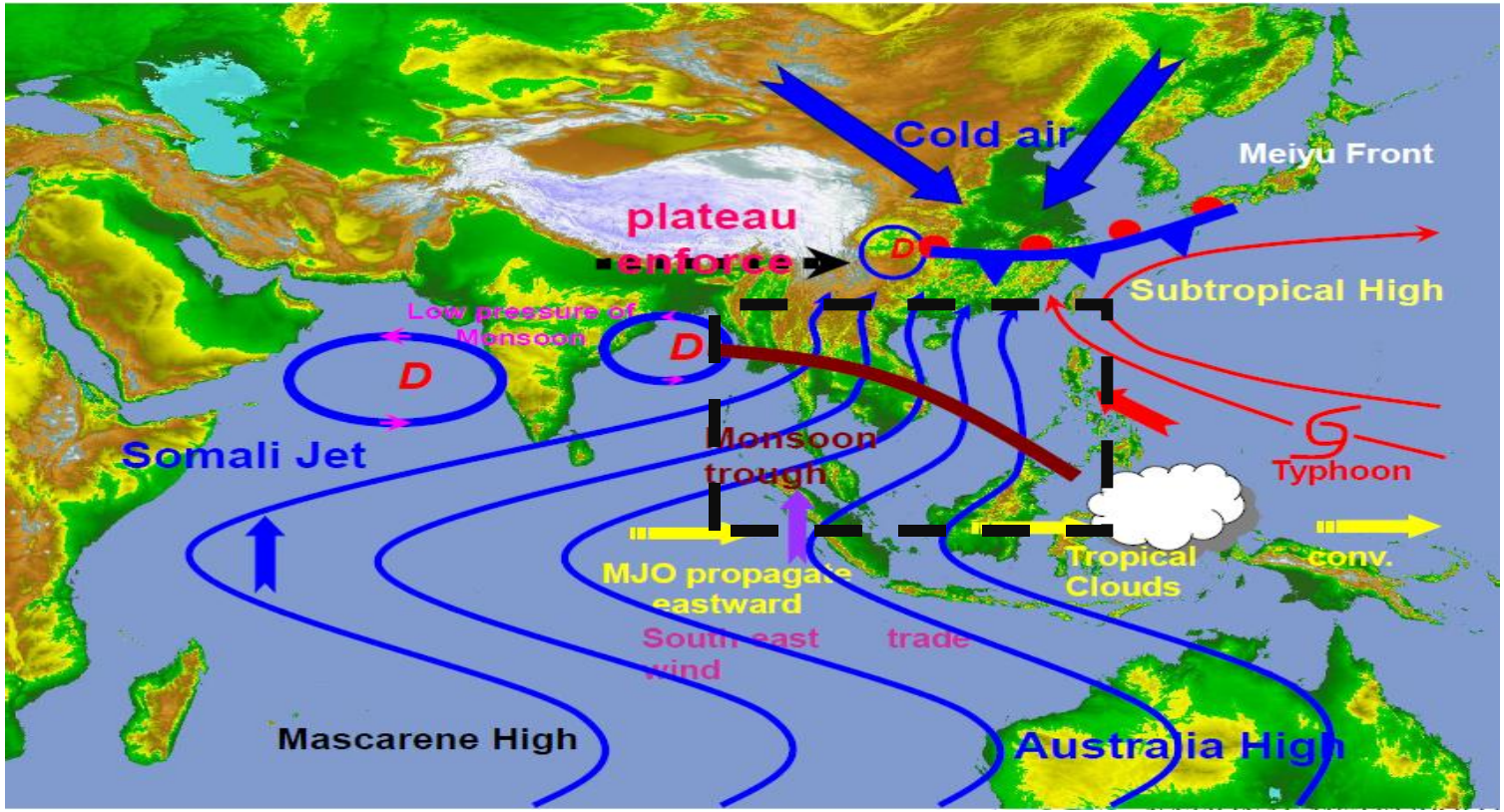
Intertropical Convergence Zone (ITCZ)



850 hPa wind field at (a) 12UTC June 14 and (b) 00UTC June 19, 2008

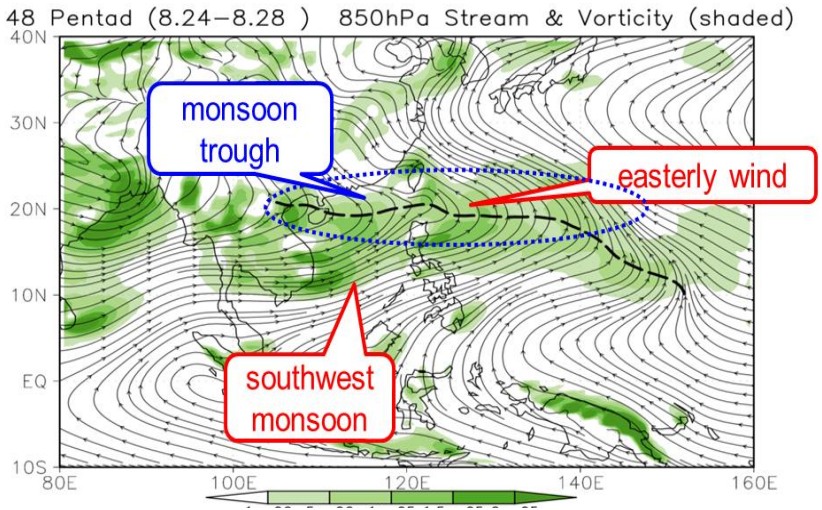
- **Disturbance was near 140° E and moved along ITCZ belt.**
- **Southwesterly strengthened and the cyclonic vorticity increased gradually, leading the DB developed into typhoon Fengshen (2008).**

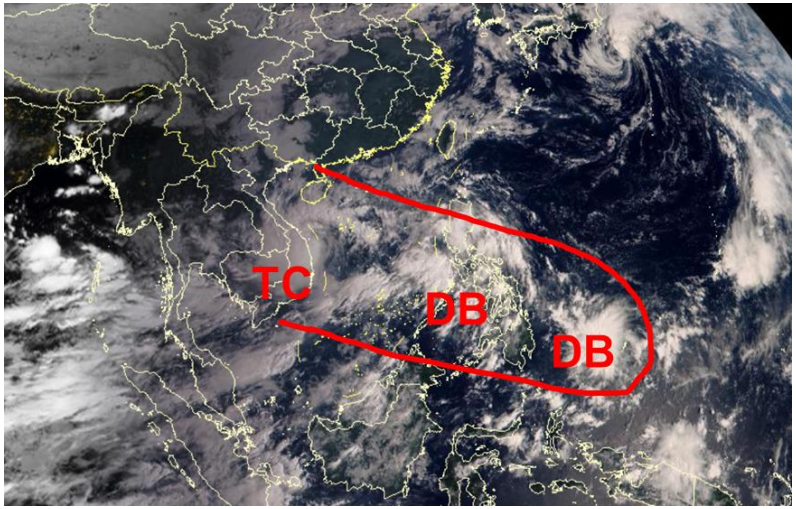
ITCZ: Monsoon Trough



Monsoon Trough: provide the most favorable environment for TC formation

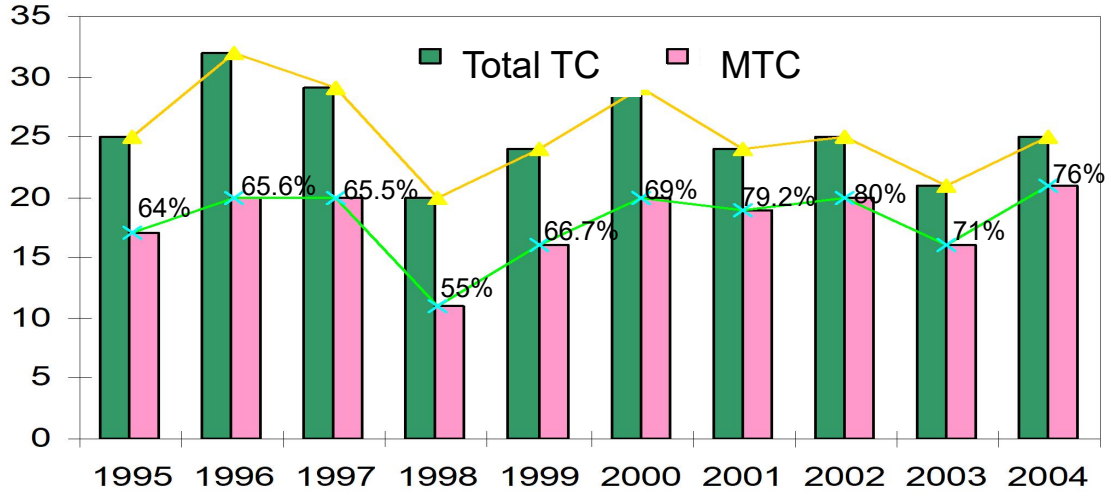
- Reduce deformation radius by the low-level larger Vorticity
  → increase the heating efficiency
- Provide a favorable vertical wind shear for the maintenance and redevelopment of MCS
  → longer life-time
  → enhancing the potential for merger, vertical development, and intensification of mesoscale vortices.
- High mid-troposphere relative humidity





The monsoon trough (MT) can determine the mean TC formation area to a large extent by providing favorable thermodynamic and dynamic large- scale conditions for TC formation.

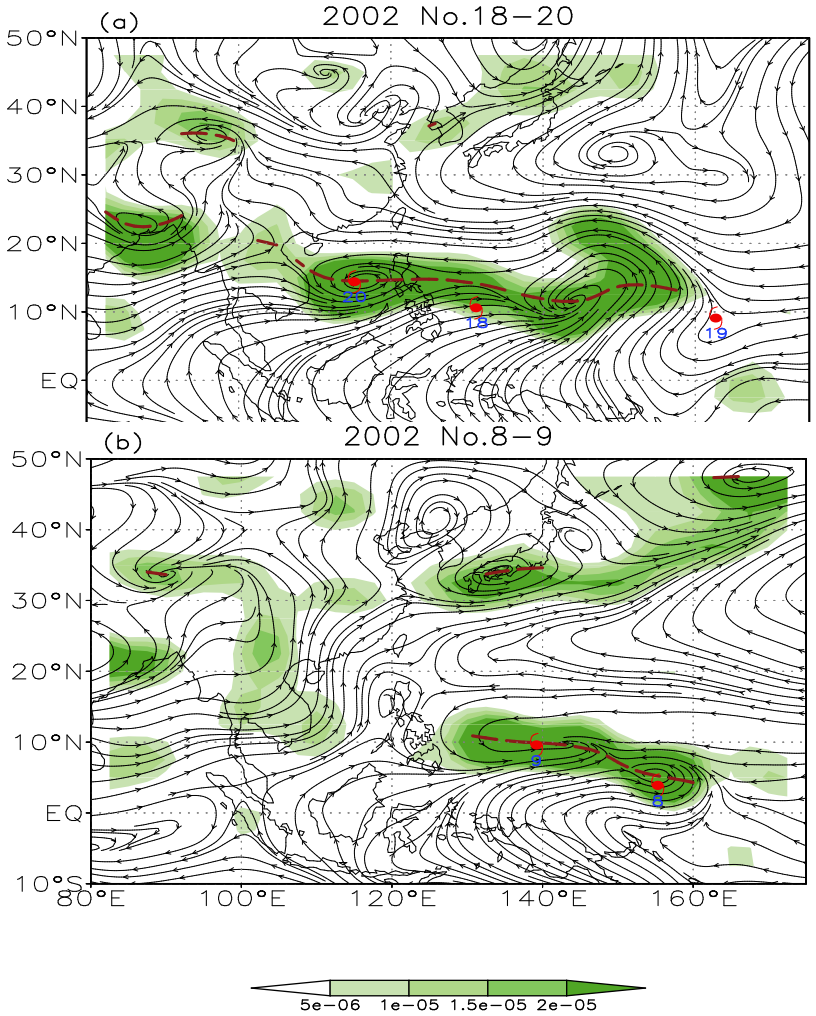
Monsoon trough and TC genesis

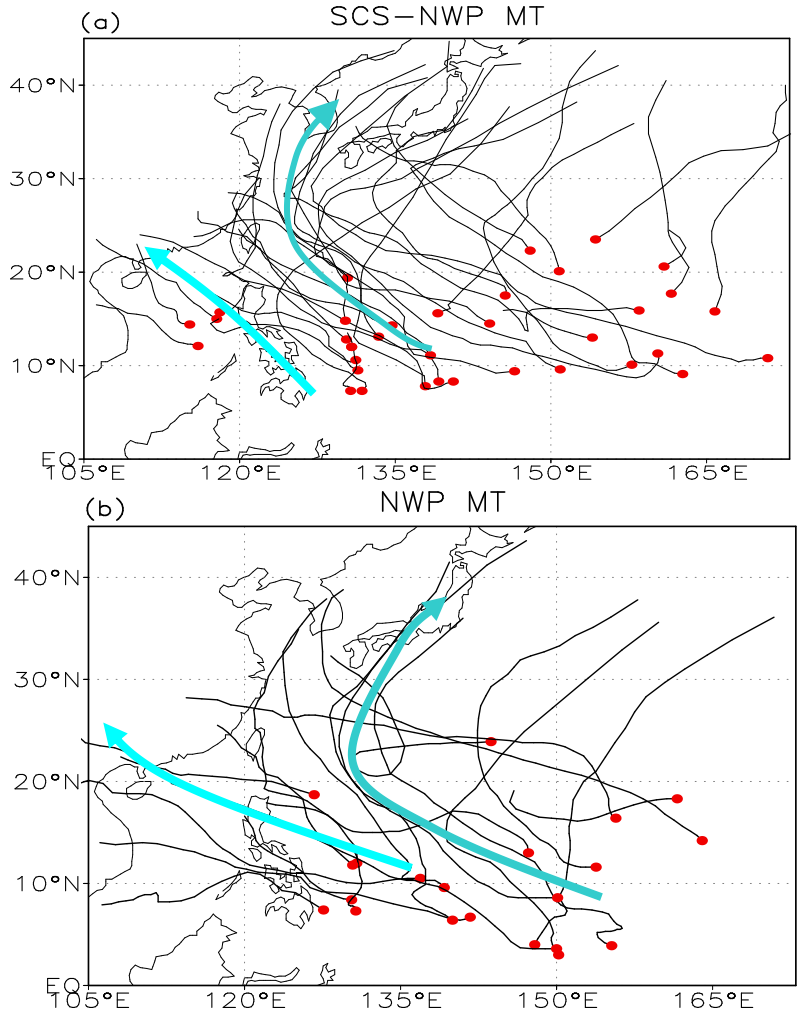


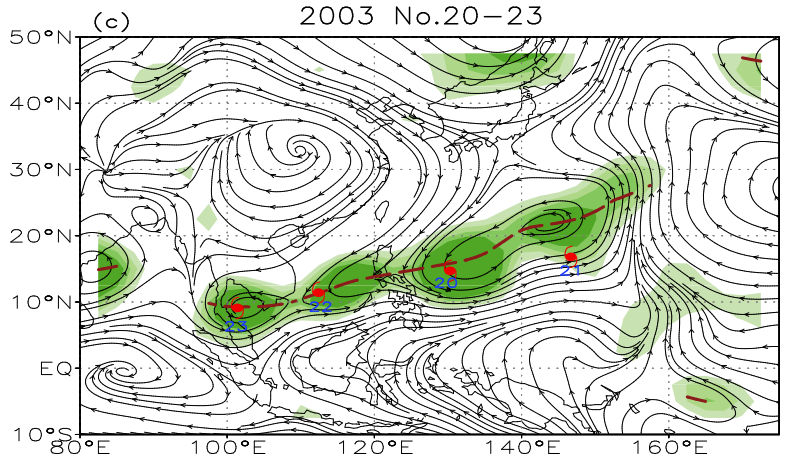
Total TC numbers and the MTC numbers during 1995-2004

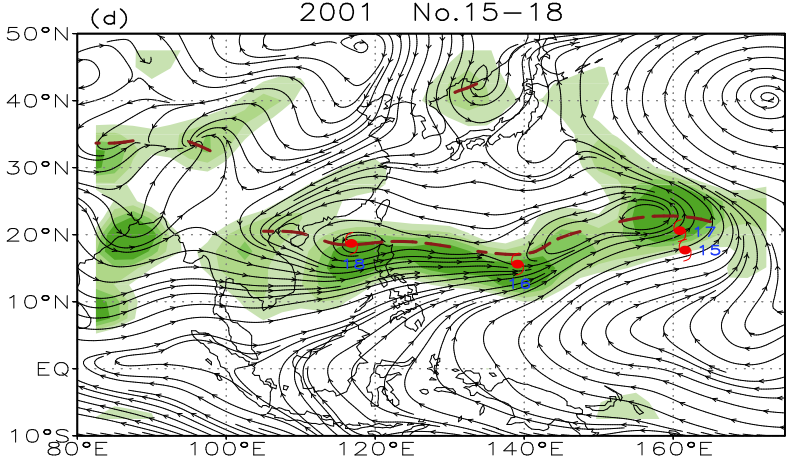
The percentage of MTCs to total TCs is about 71%.

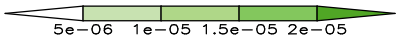
Monsoon trough is classified into 5 synoptic patterns:

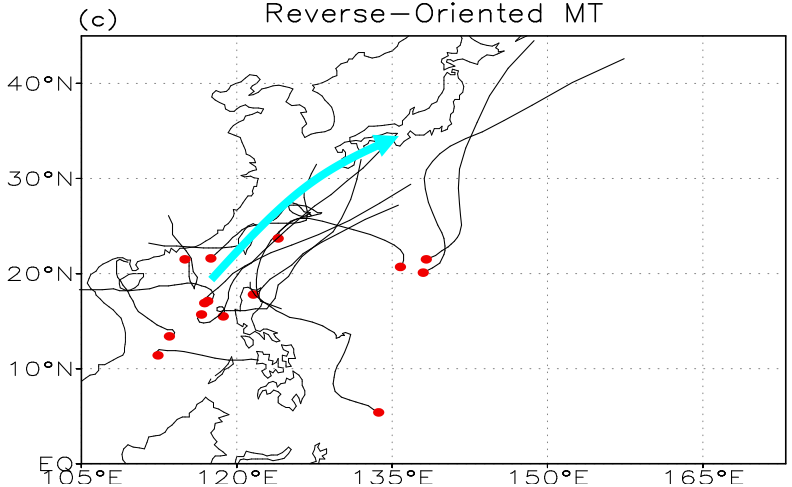

(a)
2002 No.18−20
50°N
40°N
30°N
20°N
10°N
EQ
20
18
19
(b)
2002 No.8−9
50°N
40°N
30°N
20°N
10°N
EQ
10°S
80°E
100°E
120°E
140°E
160°E
8
6
5e−06 1e−05 1.5e−05 2e−05

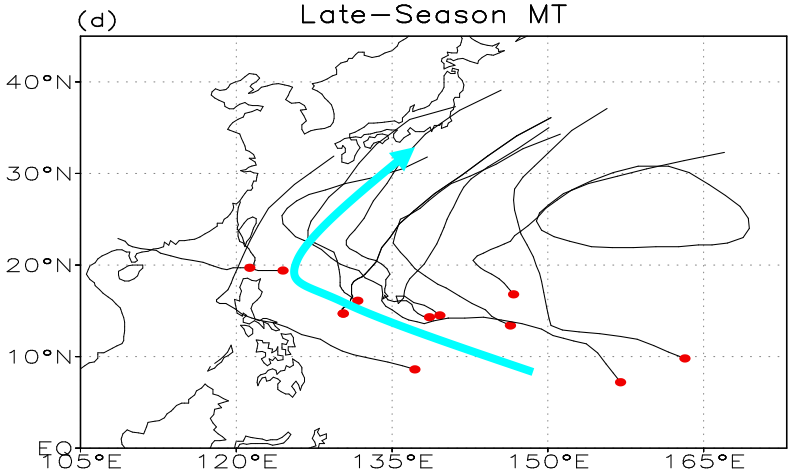

(a)
SCS−NWP MT
40°N
30°N
20°N
10°N
EQ
105°E
120°E
135°E
150°E
165°E
(b)
NWP MT
40°N
30°N
20°N
10°N
EQ
105°E
120°E
135°E
150°E
165°E

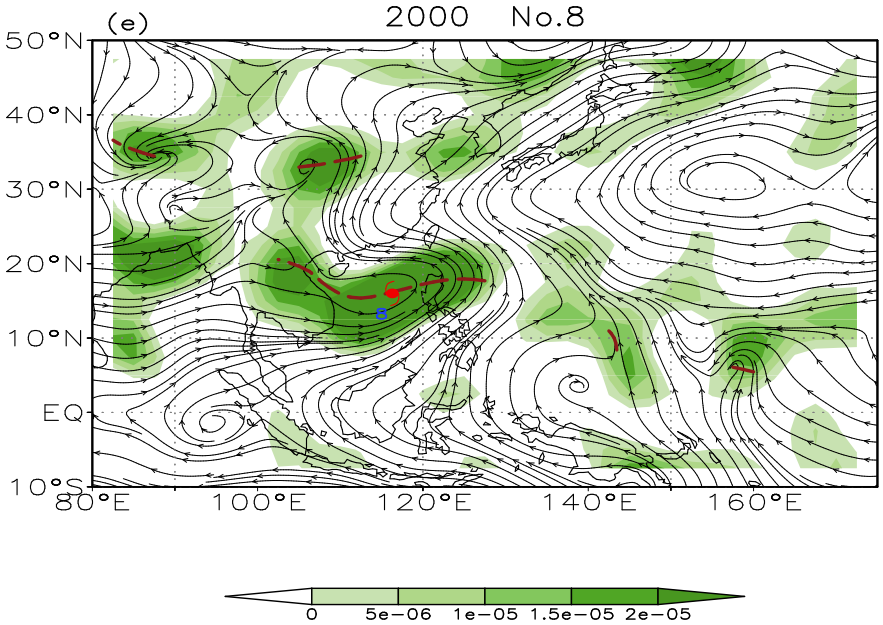

(c)
2003 No.20−23
50°N
40°N
30°N
20°N
10°N
EQ
10°S
80°E
100°E
120°E
140°E
160°E
20
21
22
23

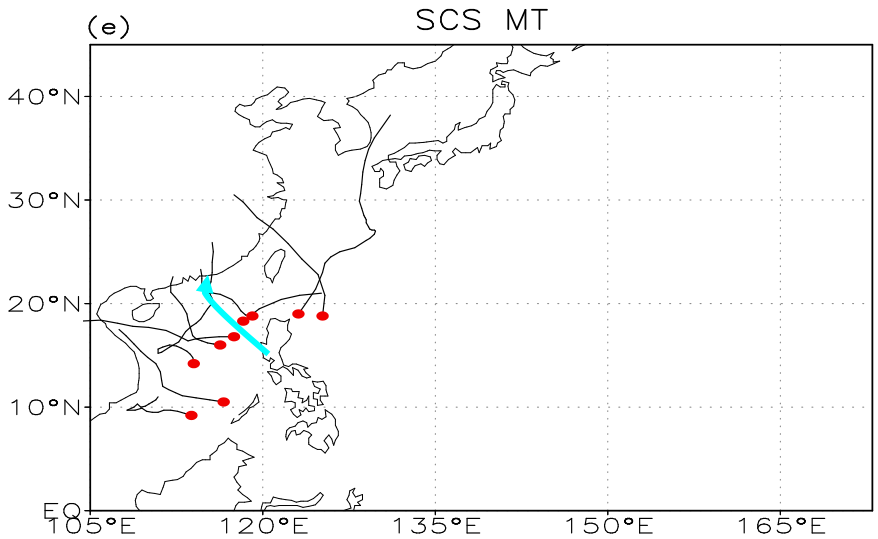

(d)
2001 No.15−18
50°N
40°N
30°N
20°N
10°N
EQ
10°S
80°E
100°E
120°E
140°E
160°E
15
16
17
18


5e−06
1e−05
1.5e−05
2e−05


(c)
Reverse−Oriented MT
40°N
30°N
20°N
10°N
EQ
105°E
120°E
135°E
150°E
165°E

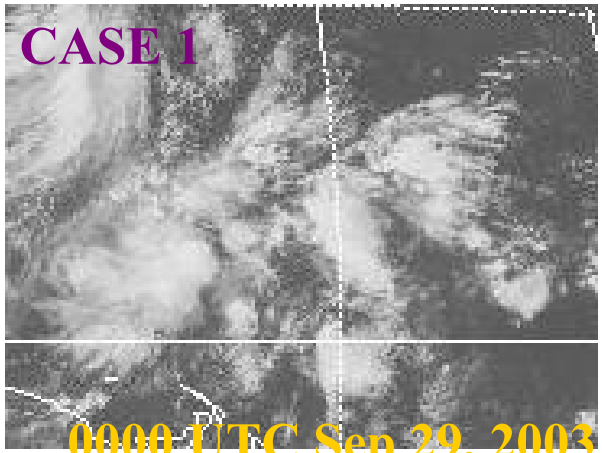

(d)
Late−Season MT
40°N
30°N
20°N
10°N
EQ
105°E
120°E
135°E
150°E
165°E

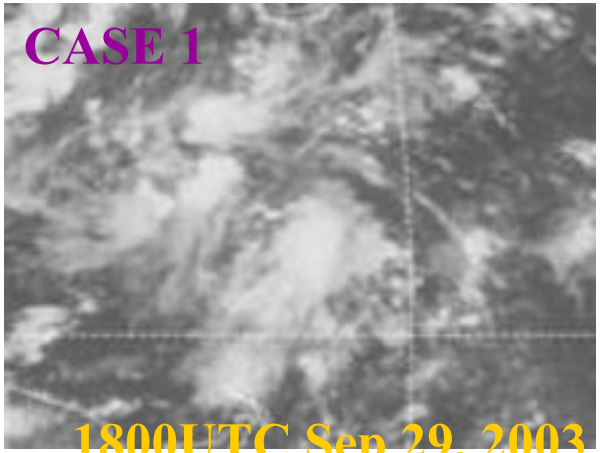


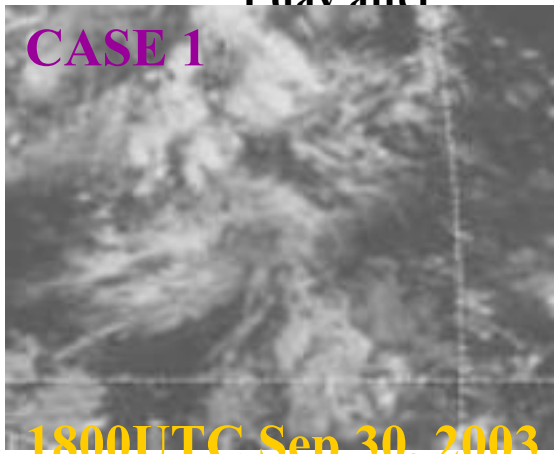


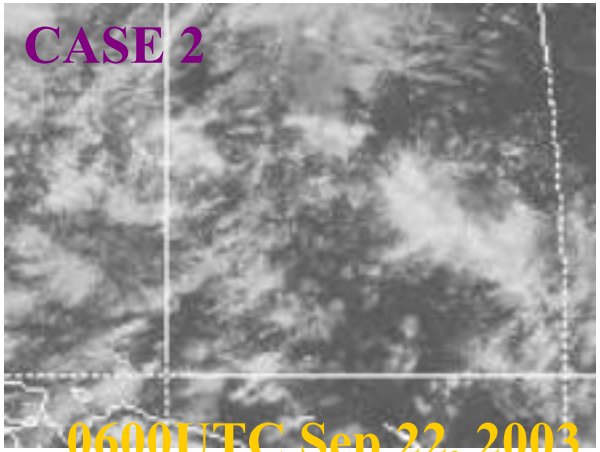
TC genesis positions are good consist with the shape of monsoon trough.

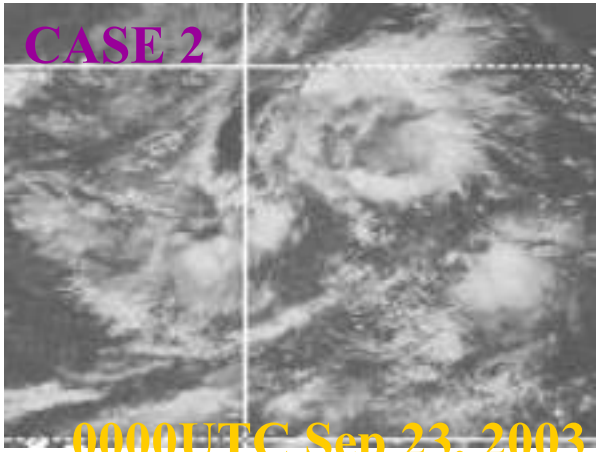
Example of non-developing and developing tropical disturbances

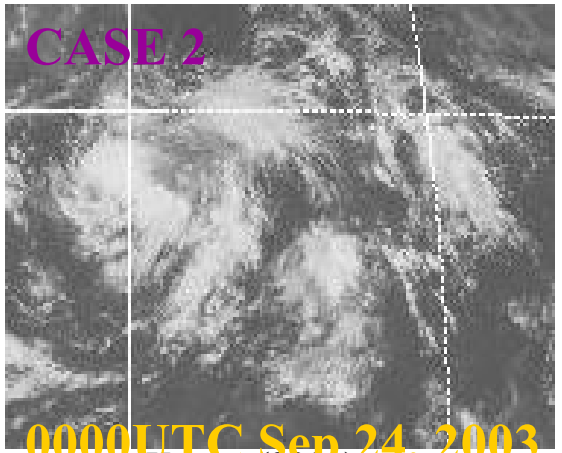












Koppu (2003)

Table 1 The statistics of the tropical disturbances in 2000-2004

年份	Total DB			Non-Monsson Trough			Monsson Trough		
	DB	D-DB	Ratio	DB	D-DB	比例	DB	D-DB	Ratio
2000	73	31	42.5%	30	11	36.7%	43	20	46.5%
2001	78	24	29.5%	34	6	14.78%	45	18	42.2%
2002	70	24	34.3%	27	5	18.5%	43	19	44.2%
2003	66	22	33.3%	29	6	20.7%	37	16	43.2%
2004	44	25	55.5%	11	4	36.4%	34	21	61.8%
AVE	**66.4**	**25**	**37.6%**	**26.2**	**6**	**23.7%**	**40.2**	**19**	**47.3%**

The developmental probability of DB in monsoon trough is much higher than non-monsoon trough. Therefore, TC genesis is sensitive to larger-sacle circulations.

The statistics of TC genesis associated with the five monsoon trough pattern

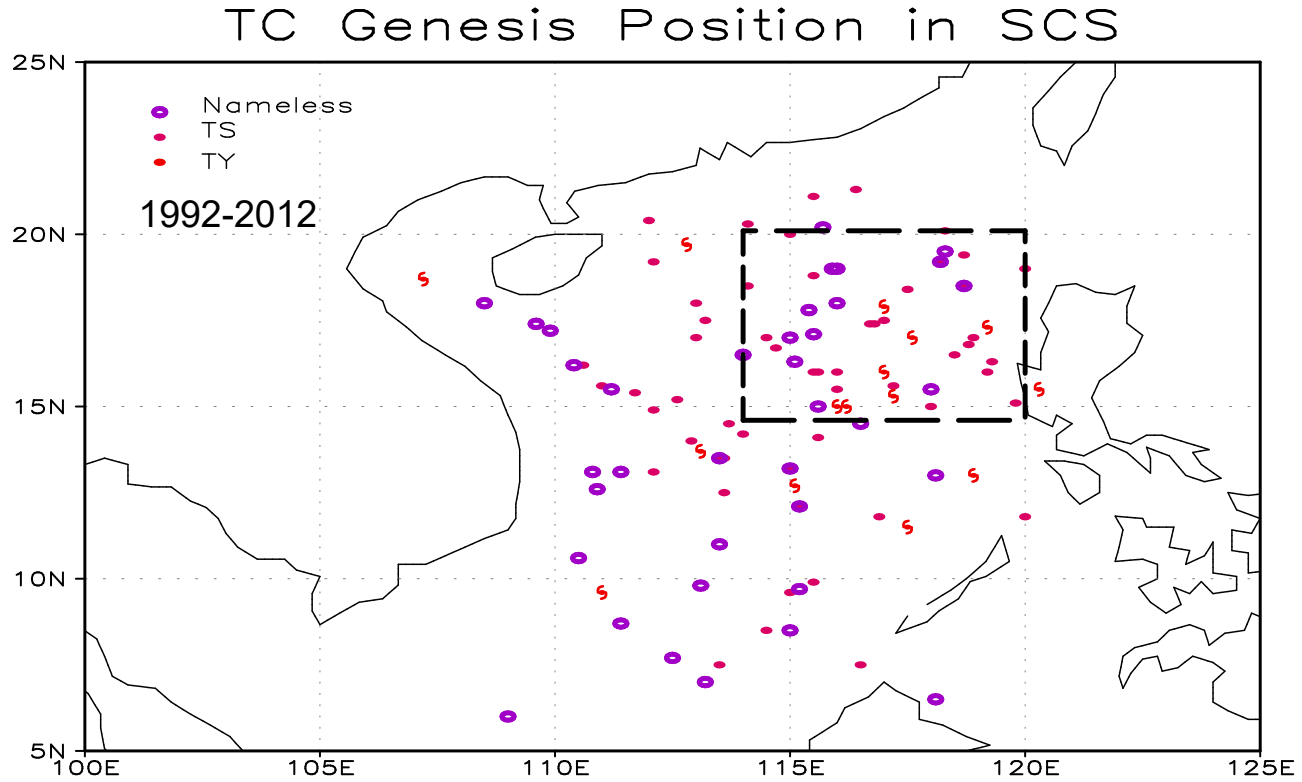
MT Pattern	TC	Radio	DB	Develop probability
SCS-NWP	69	38.5%	73	50.7%
NWP	39	21.8%	39	59.0%
RO	33	18.4%	28	60.7%
LS	23	12.8%	37	30.0%
SCS	15	8.4%	25	32.0%

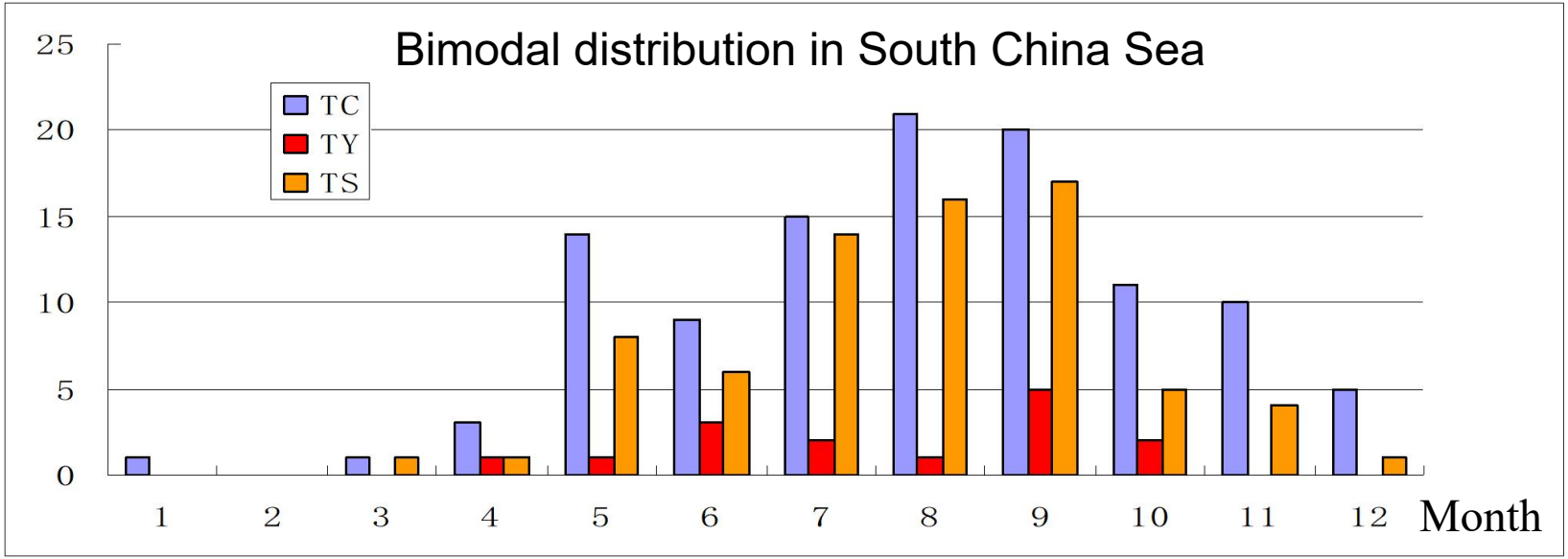
Develop probability is highest

Develop probability is lowest

The environmental conditions do not directly determine the process of genesis, but may certainly affect the probability of its happening.

The location of TCs genesis in South China Sea





- **TC genesis mainly occur during April and December, but very few TC genesis occur during January and March.**
- **The number of TC genesis in SCS increases from May when SCS Monsoon starts, and the number is highest in August.**
- **TC genesis frequency has two peaks in South China Sea, in May and August.**

The Activities of Tropical Disturbance

South China Sea

Only 25.2% DB → TS

1321 **WUTIP 45m/s**

Northwest Pacific Ocean

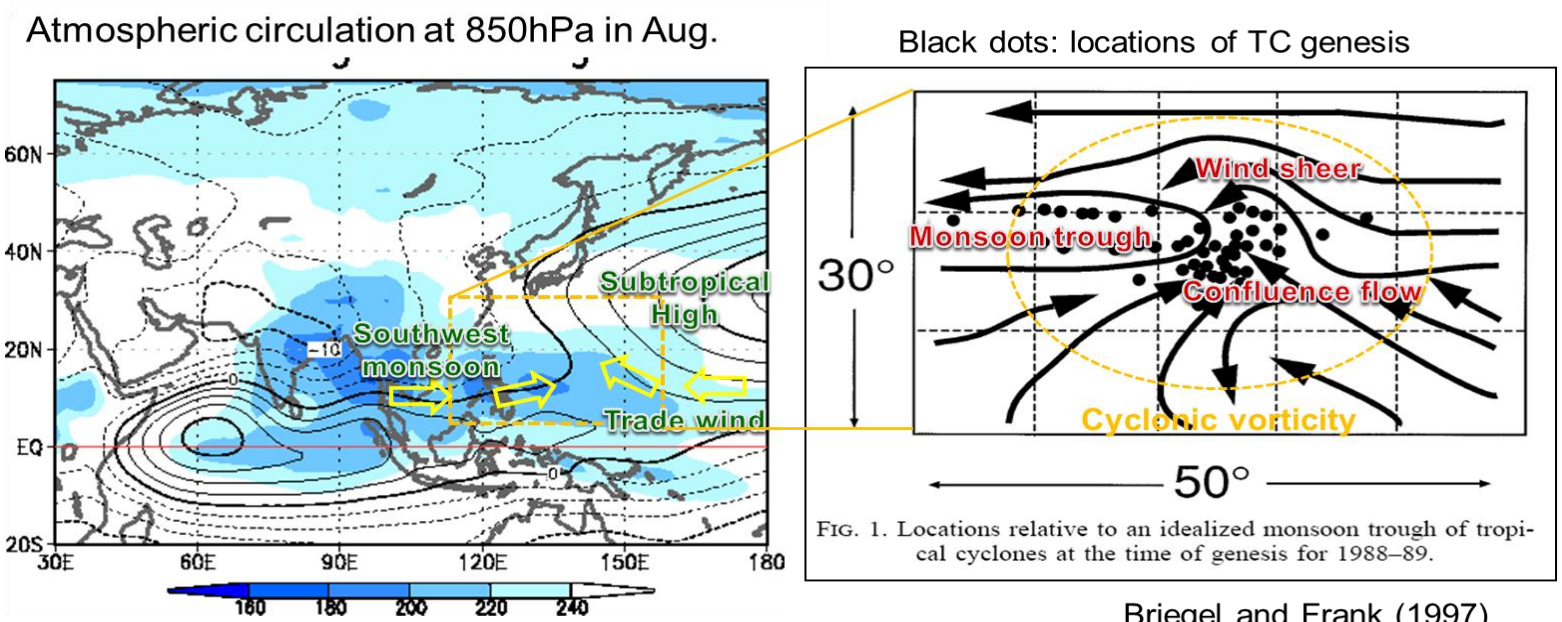
About 40.7% DB → TS

Only 25.2% tropical disturbances (DB) can develop into TC in SCS, and 11.6% DB can only intensify tropical depression (TD), but can not further develop into TS, while most of DB（about 63%) finally dissipate. Genesis cases <<Non genesis case

The probability of DB in South China Sea that can develop into TS or TD is much lower than that in Northwest Pacific Ocean, and only few TCs can further develop into tropical typhoon or super typhoon.

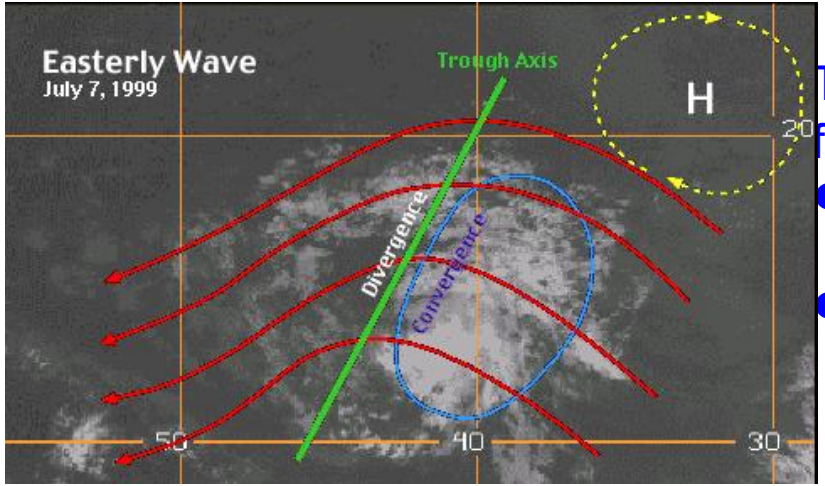
TC Genesis over monsoon trough In SCS-NWP （Summary）

- In the SCS-western North Pacific, southwest monsoon and easterly trade winds form monsoon trough during May and October.
- Combined with warm Pool, monsoon trough can provide the most favorable conditions for TC genesis. The develop probability of DB is higher in monsoon trough than non- monsoon trough.



Briegel and Frank (1997)

Easterly waves (18%)

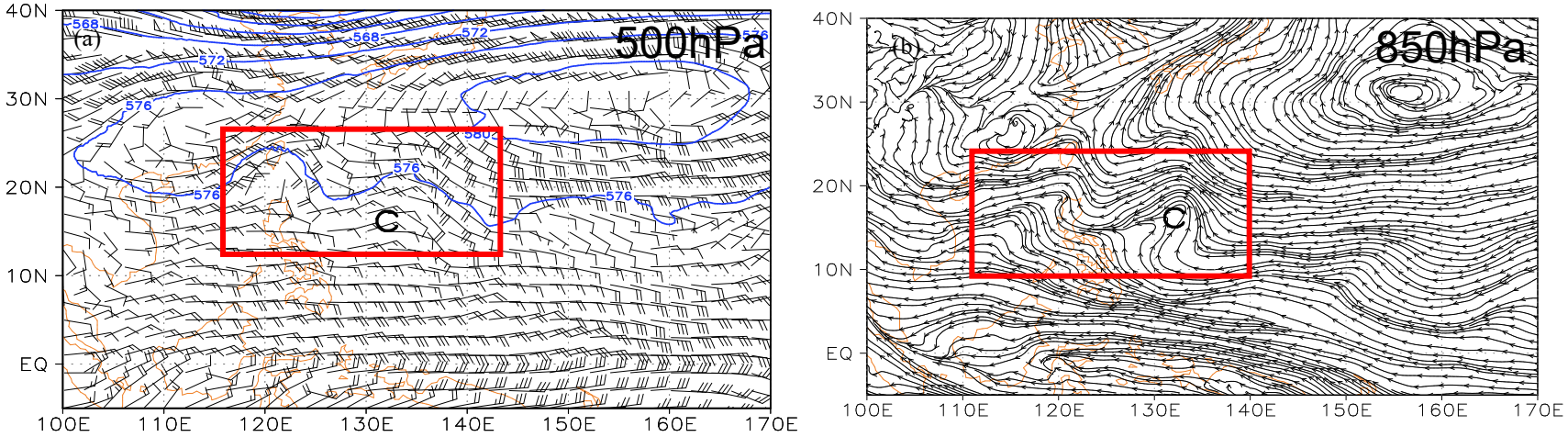


The easterly wind wave has two functions for TC formation:

- (1) the easterly wave can be a tropical disturbance that maybe develop into a TC;
- (2)As a triggering Mechanism, the easterly wave can generate other tropical disturbances to develop into TCs.

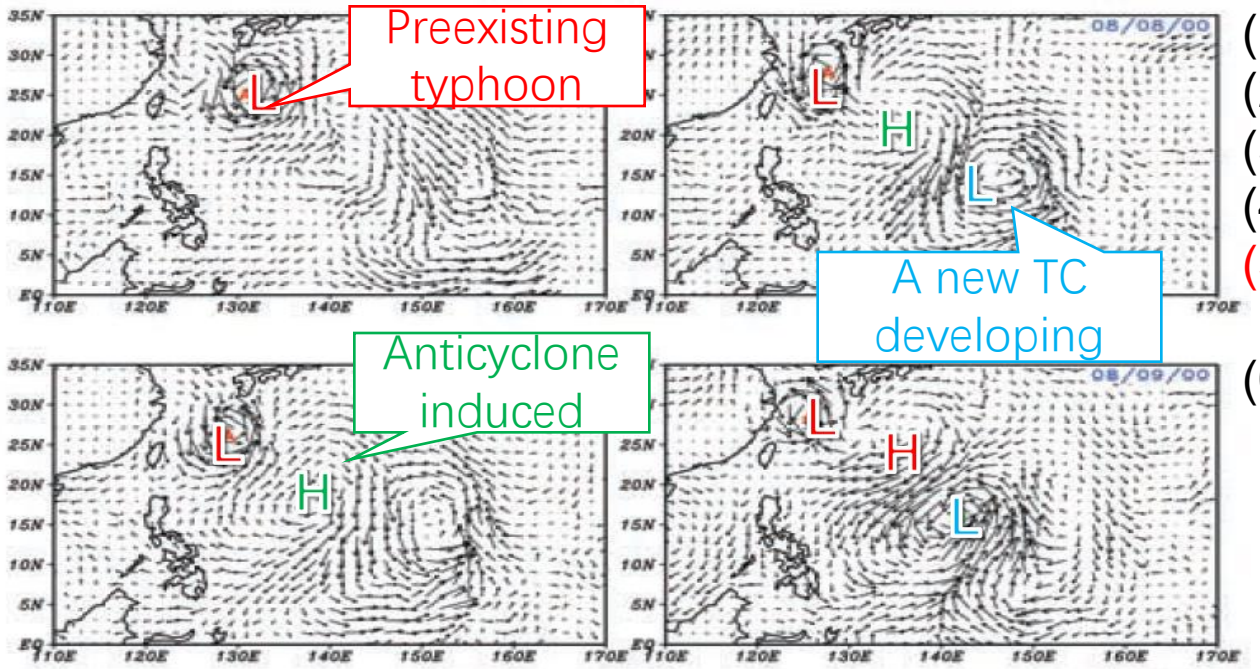
- The easterly wave is a tropical wave moving (an average speed of 20 km/h) from east to west in the deep easterly belt south of subtropical high, also known as easterly trough.
- Its horizontal wavelength is about 2000 to 4000 km, and its maximum intensity generally occurs between 700 to 500 hPa isobaric surfaces
- In satellite imagery they appear as concentrated groups of clouds mostly on the east side of the inverted trough.

Easterly waves (18%)



The wind field and geopotential height of 500hPa (a) and streamline of 850hPa (b) at 12hour before the formation of typhoon Dan (1999)

Rossby wave dispersion (8%)



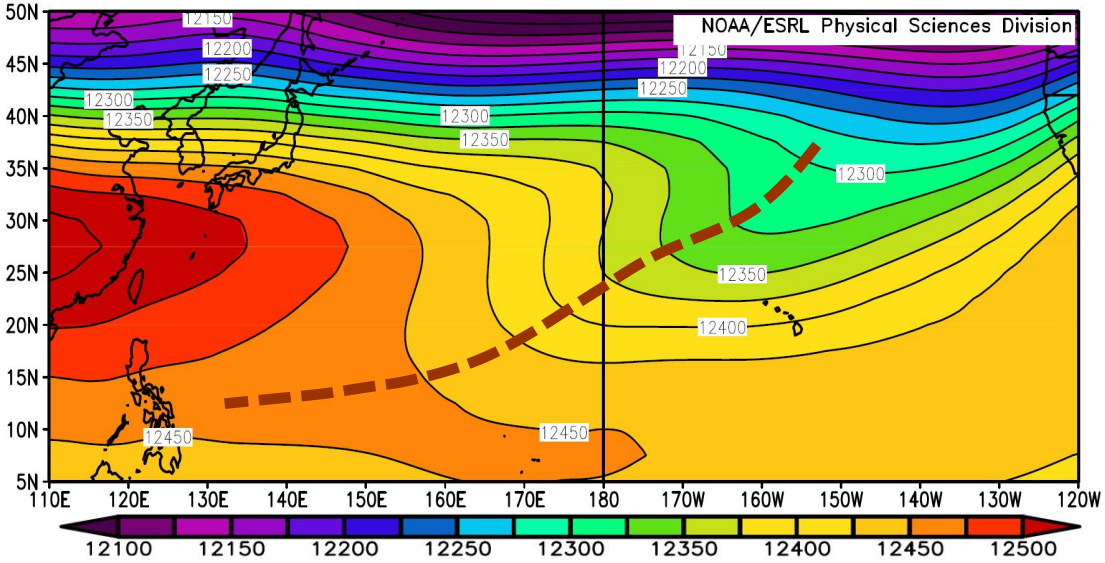
(1)Monsoon shear line
(2)Monsoon confluence region
(3)monsoon gyre
(4)Easterly waves
(5)Rossby energy dispersion from a preexisting typhoon
(6)Upper tropospheric trough

Li et al. (2003)

Time evolution of Rossby wave train associated with the energy dispersion of TC Jelawat. “L" represents the center location of Jelawat that formed on 1 August 2000. “L" represents the center location of a new TC named Ewiniar that was generated on 9 August 2000 in the wake of the Rossby wave train of Jelawat.

Tropical Upper Tropospheric Trough (TUTT)

- In summer, the TUTT formed in the upper troposphere (at about 200 hPa) over the central North Pacific and the central North Atlantic, also known as the mid ocean trough.
- TUTT is planetary scale weather system, the length of trough line from east to west can reach more than 70 latitudes.

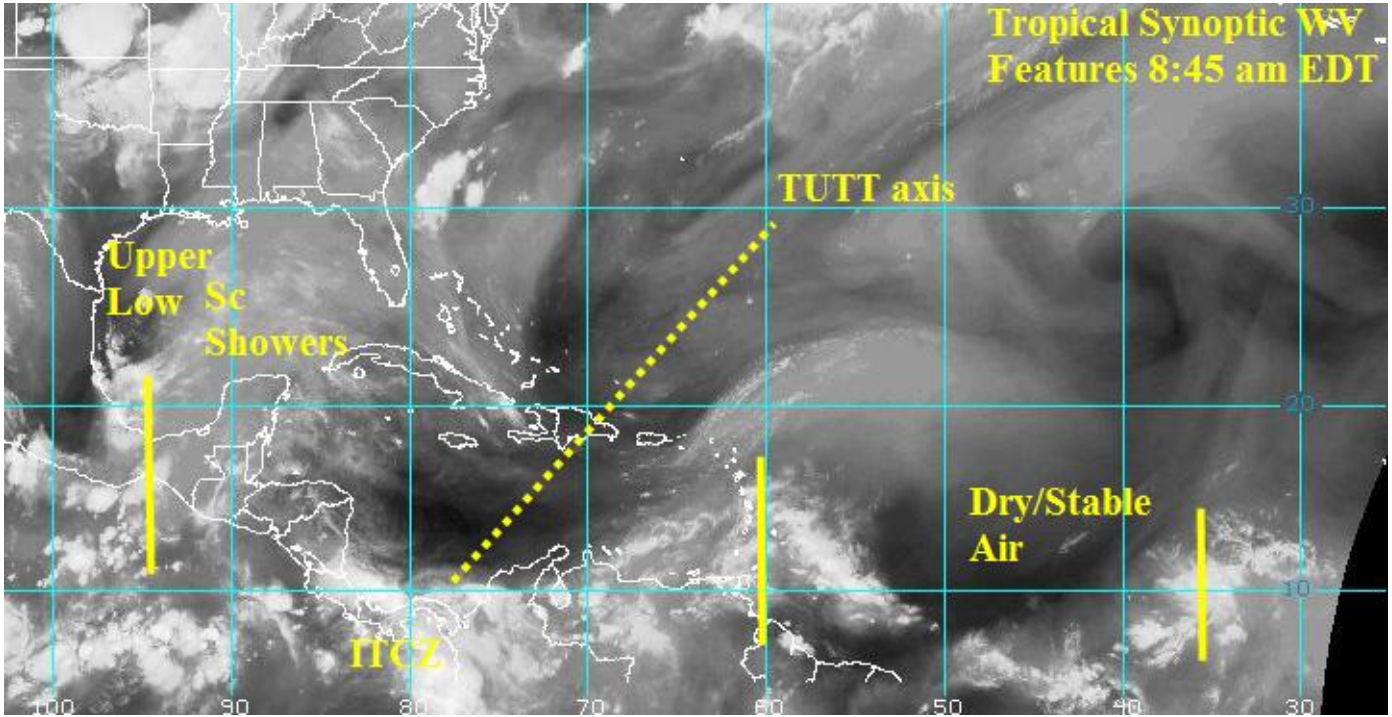


(1)Monsoon shear line
(2)Monsoon confluence region
(3)monsoon gyre
(4)Easterly waves
(5)Rossby energy dispersion from a preexisting typhoon
(6)Upper tropospheric trough

Mean height for July at 500hPa

Features of TUTT on the satellite image

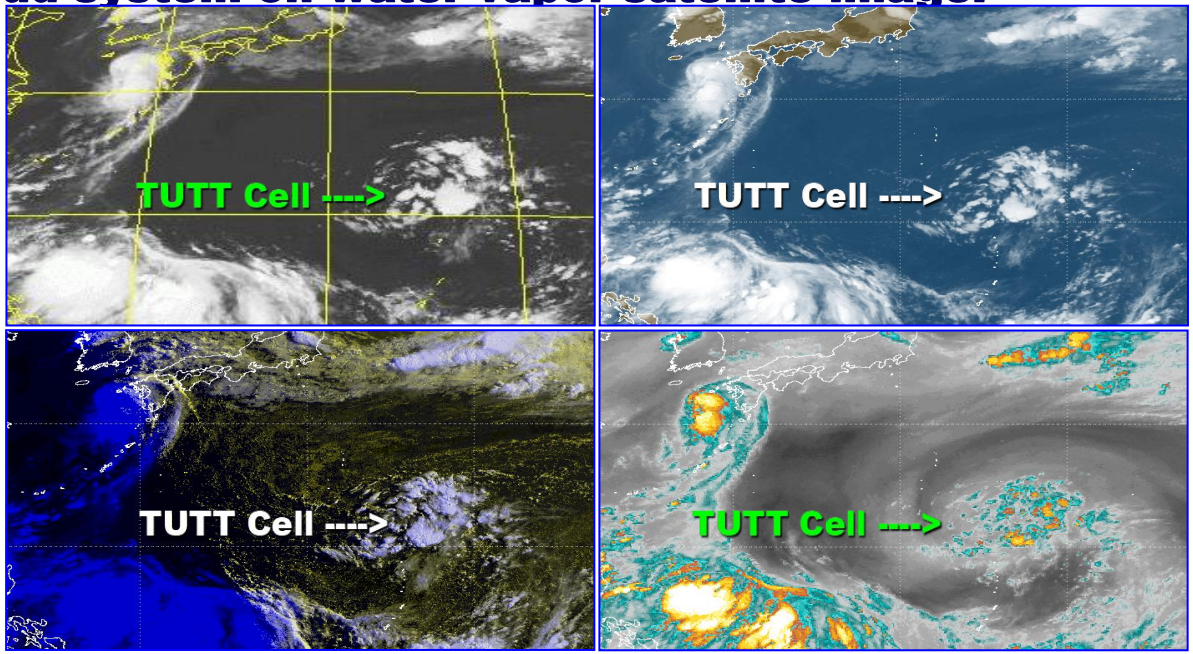
- ✓ **TUTT on a satellite water vapor image.**



Features of TUTT on the satellite image

✓Unorganized cloud system on at the infrared and visible satellite images

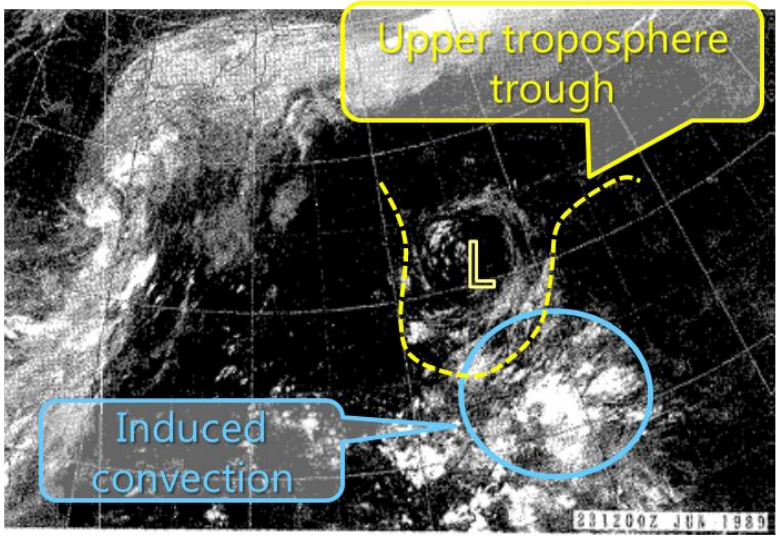
✓Vortex cloud system on water vapor satellite image.

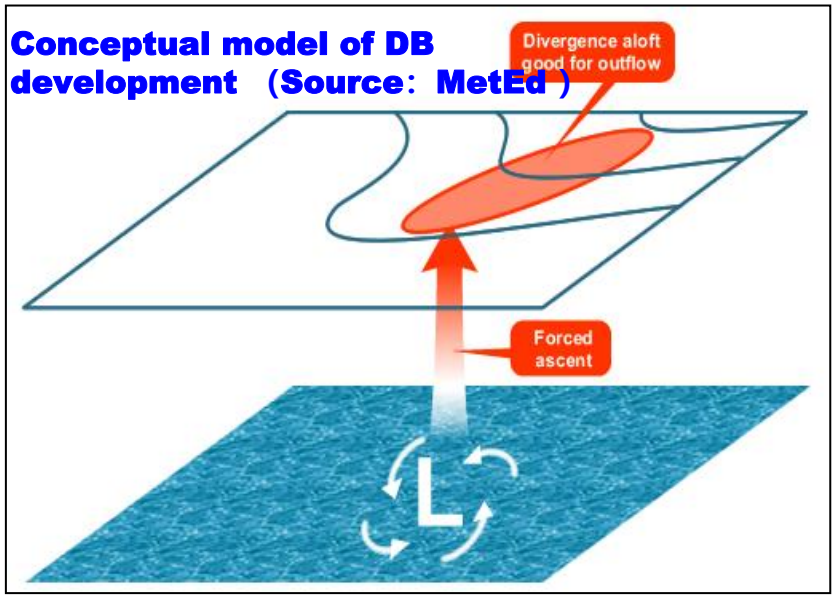


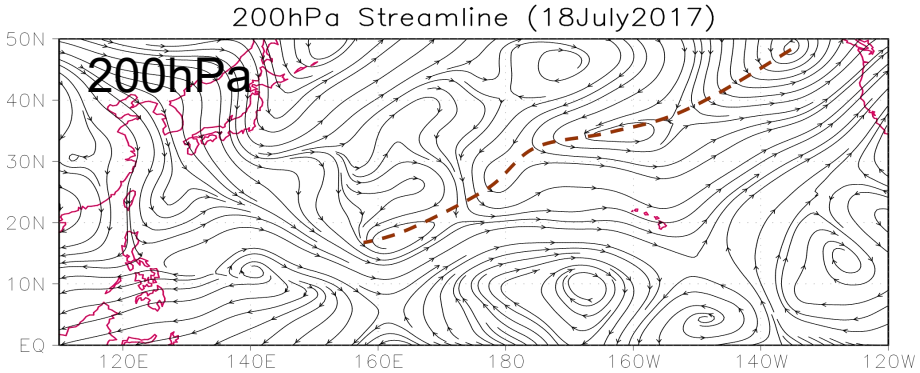
- When the mid-latitude jet stream pronouncedly meanders, a cut-off low starts to migrate equatorward. (TUTT-cell).
- TUTT cell can extend downward and trigger the occur of tropical disturbances.

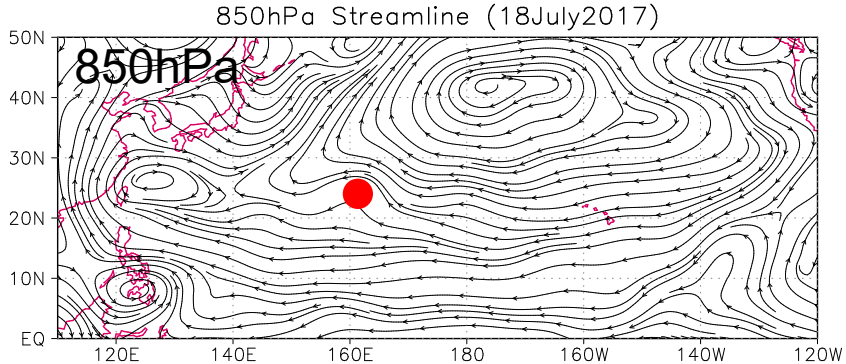
Tropical Upper Tropospheric Trough (TUTT) and TC genesis

- TUTT they can either help or hinder tropical cyclone development depending on where the surface low is developing in relation to the upper trough.
- Tropical Upper Tropospheric Trough (TUTT) can strengthen the upper-level outflow of the storm and assists tropical cyclone genesis by providing additional forced ascent near the storm center.

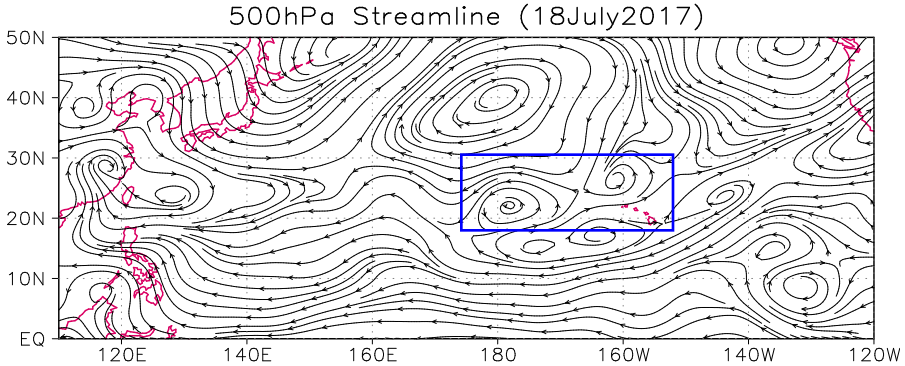


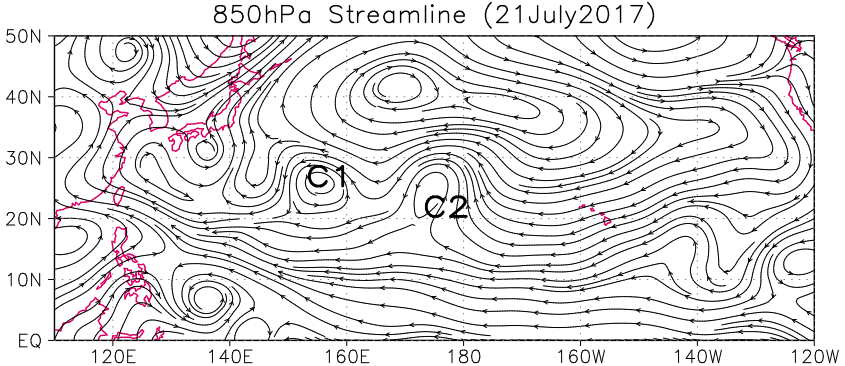






The streamline of 200hPa (a) and 850hPa (b) at 72 hours before the formation of typhoons Noru and Kulap (2017)





The streamline of 500hPa (a) and 850hPa (b) at 12 hours before the formation of typhoons Noru and Kulap (2017)

Tropical Upper Tropospheric Trough (TUTT)

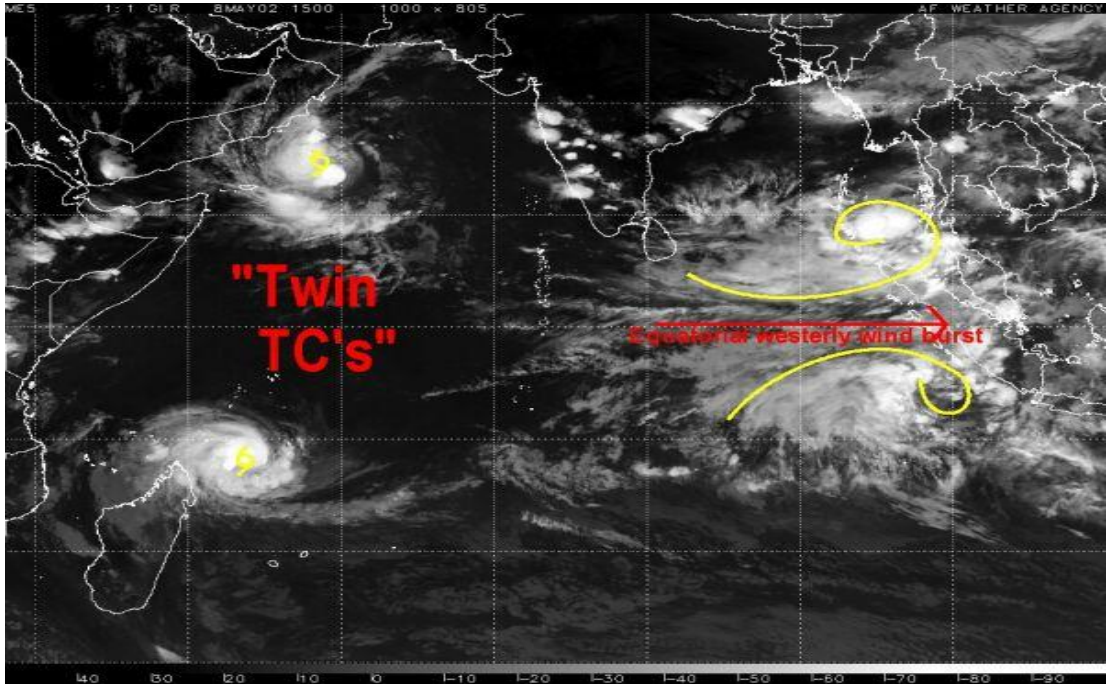
- Tropical Upper Tropospheric Trough (TUTT) cell can extend downward and trigger the occur of tropical disturbances.

Other: Tropical Waves

- Madden Julian Oscillation (MJO, Madden and Julian, 1994)
- Equatorial Rossby Waves
- Mixed Rossby Waves
- Kevin Waves
- Easterly waves

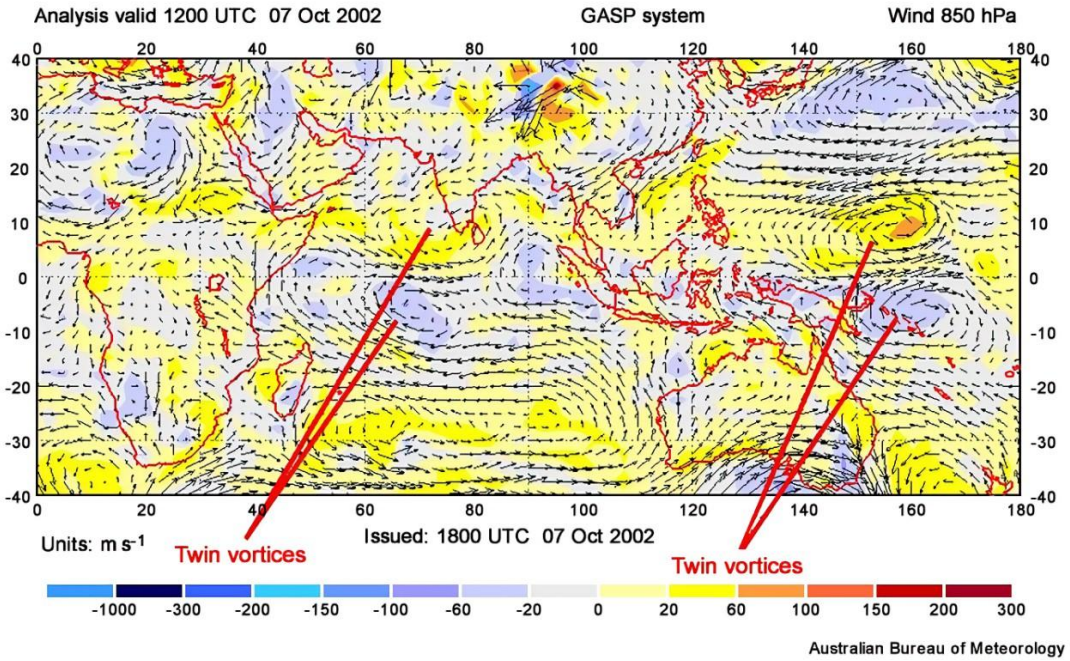
- ✓ ***The waves can modulate the time and place of cyclone formation.***
- ✓ ***TC genesis often occur when one or more of these waves accelerate the process.***
- ✓ ***The waves can accelerate the cyclogenesis process within a climatologically favorable region by enhancing the amount of the lager-scale convection in the region as well as the low-level rotation.***

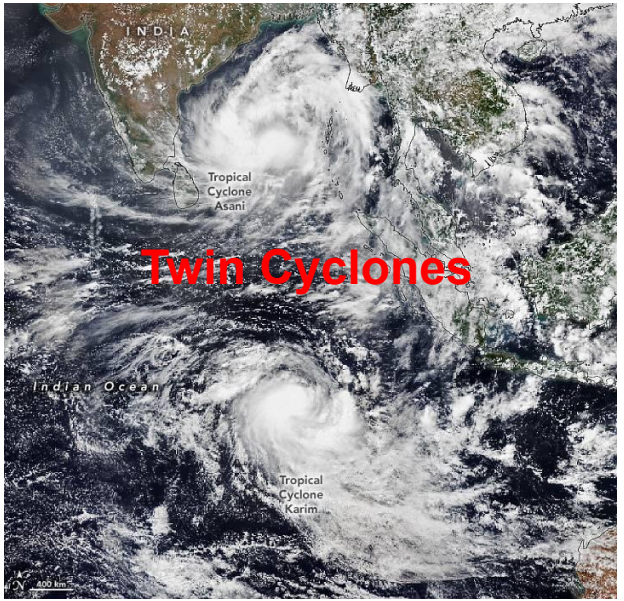
Other: Tropical Waves



***Equatorial Waves*: An example of the tropical cyclone genesis associated with the equatorial Rossby waves embedded in an MJO event over the Indian Ocean.**

Other: Equatorial Waves





Twin tropical cyclones that straddle the equator at formation have a flow structure suggestive of equatorial Rossby waves

OUTLINE

- Climate Background
- Large-scale Conditions Associated with TC Genesis
- The Features of MCSs Associated with TC Genesis
- TC Genesis Forecast
- Conclusions

Stepwise necessary requirements for TC genesis

Background Requirements to make Tropical Cyclone Formation a Possibility

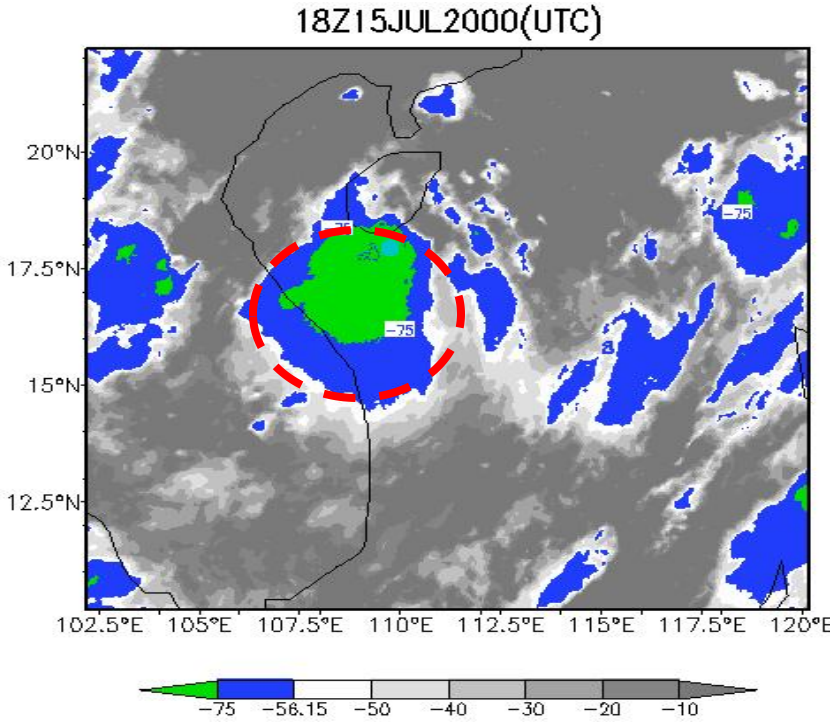
1. Climatology is right (i.e., region, season, SST, etc.)
2. Synoptic Flow pattern is right (monsoon trough or high vorticity with small vertical wind shear, etc.)
3. Active Mesoscale Convection System (MCS) is present within a cloud cluster system

Gray(1998)

- Mesoscale dynamics of organized convection may play an important role.

- **How is Features of MCSs Associated with MTC genesis?**

MCS &TC Genesis



The definition of MCS

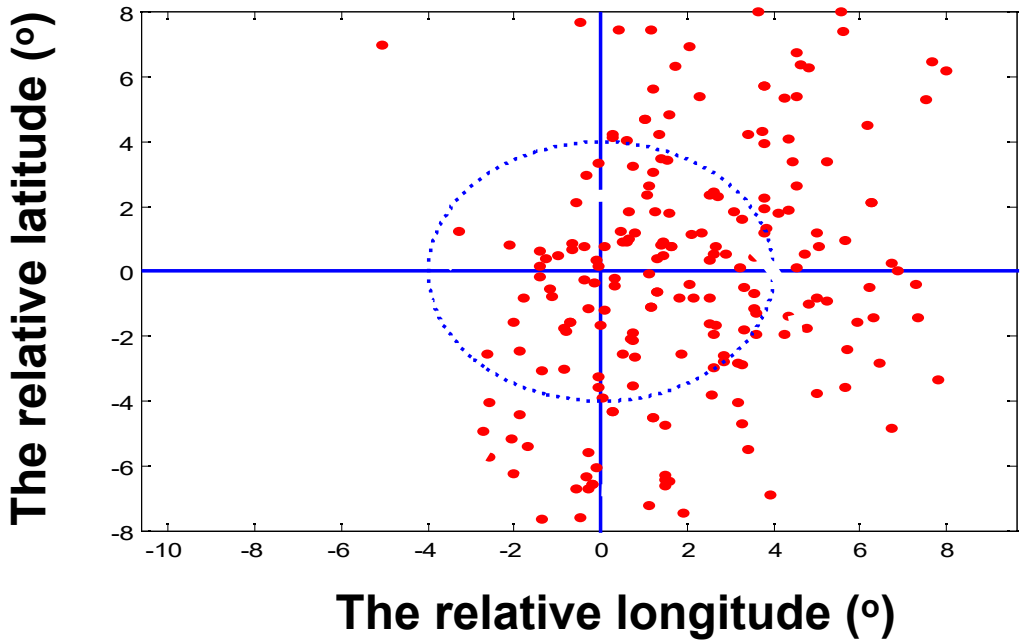
- Deep convection: TBB <-56.15 ^{o}C (214K)
- Area>4x10^{4} km^{2}
- Eccentricity>0.5
- Lift time>3 hours

Ritchie and Hollad (1997)

The statistics of MCSs activity during MTC genesis (2000-2004)

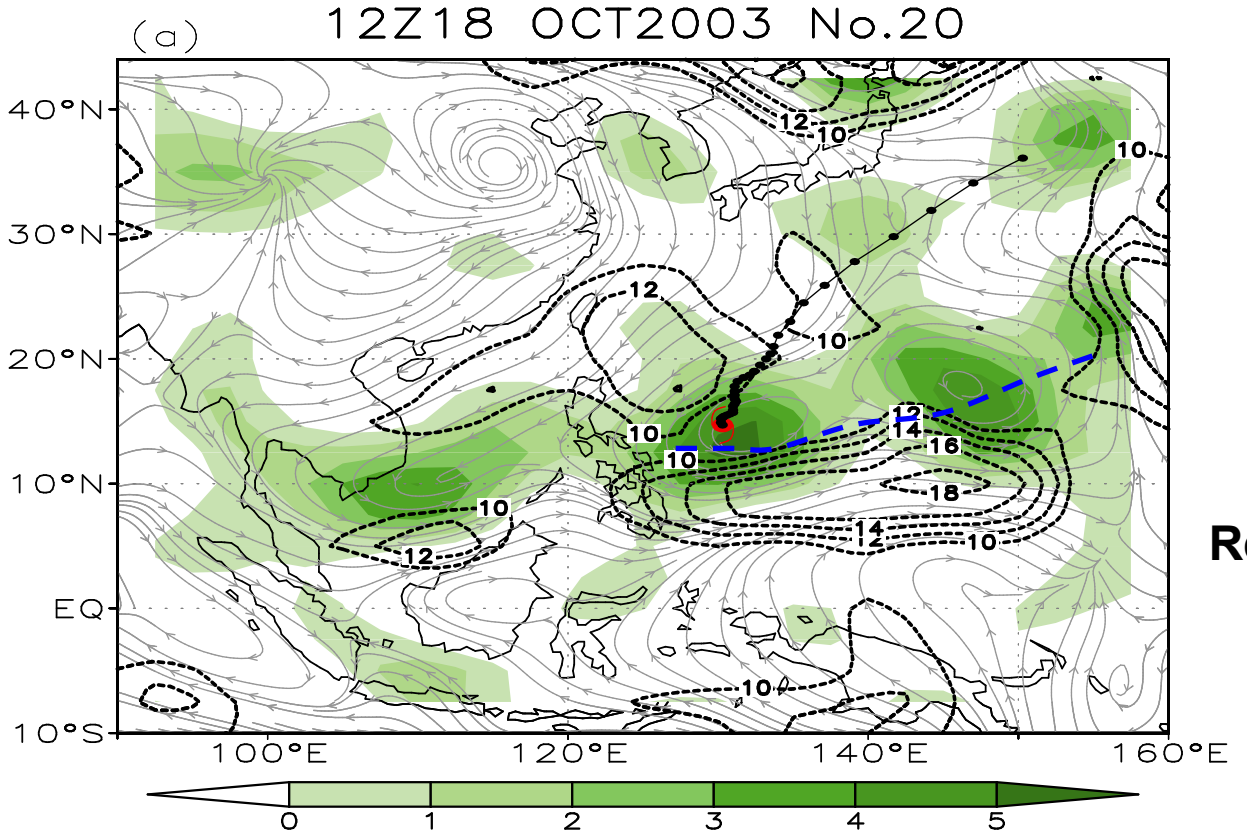
MT Pattern	MCS number	Lift time of MCS (h)	Minmum TBB（°C）	radio of Multi MCS	Radio of Muti MCS at same time
SCS-NWP	2.7	14.0	-84.4	92.6%	59.3%
NWP	2.9	13.8	-85.7	89.0%	65.0%
RO	2.3	16.3	-83.7	93.3%	46.7%
LS	2.8	16.4	-87.7	90.0%	70.0%
SCS	3.1	13.5	-86.4	100%	75.0%
AVE	2.7	14.1	-85.6	91.1%	59.4%

- **During MTC formation, there are usually more than two MCSs during TC genesis stage.**



- **MCSs that are associated with TC genesis are mainly within 4° around TC genesis position (54.3%).**
- **More MSC occur in northeast quadrant while less MCS occur in northwest quadrant.**

Ketsana (2003)



Reverse-oriented MT

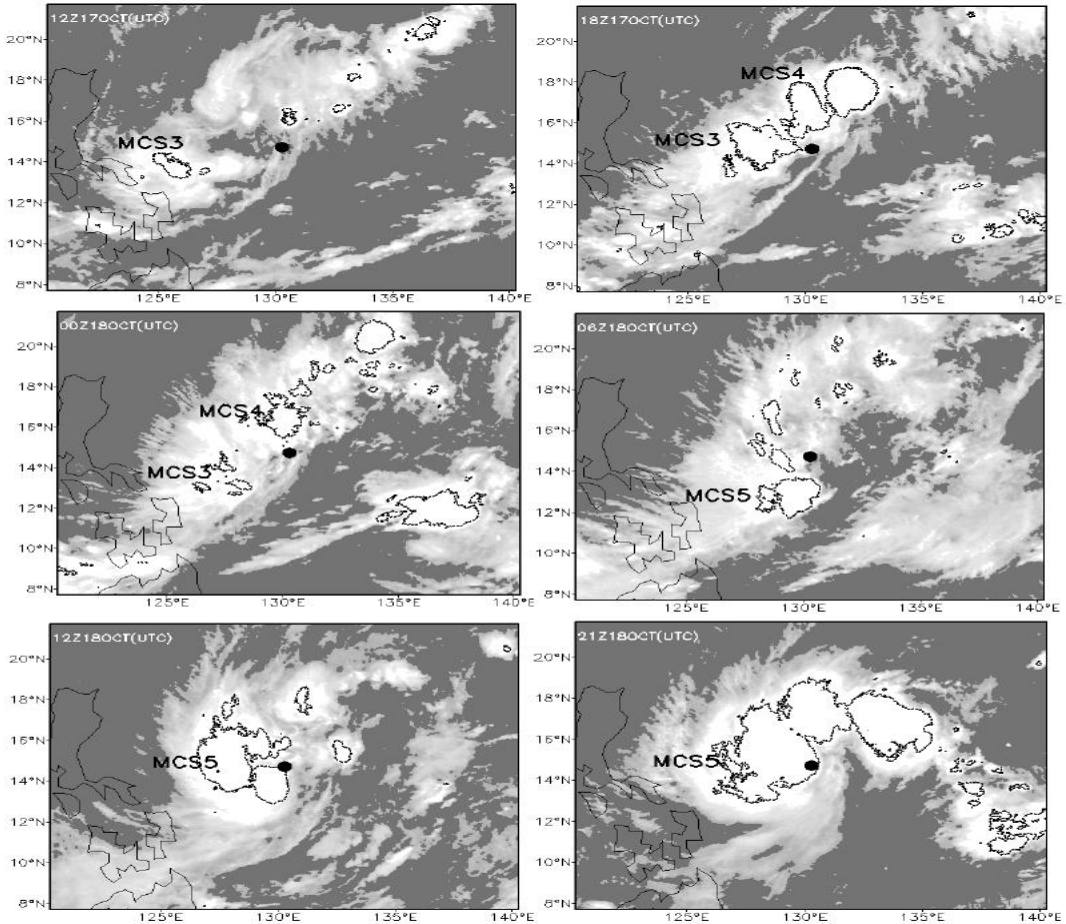
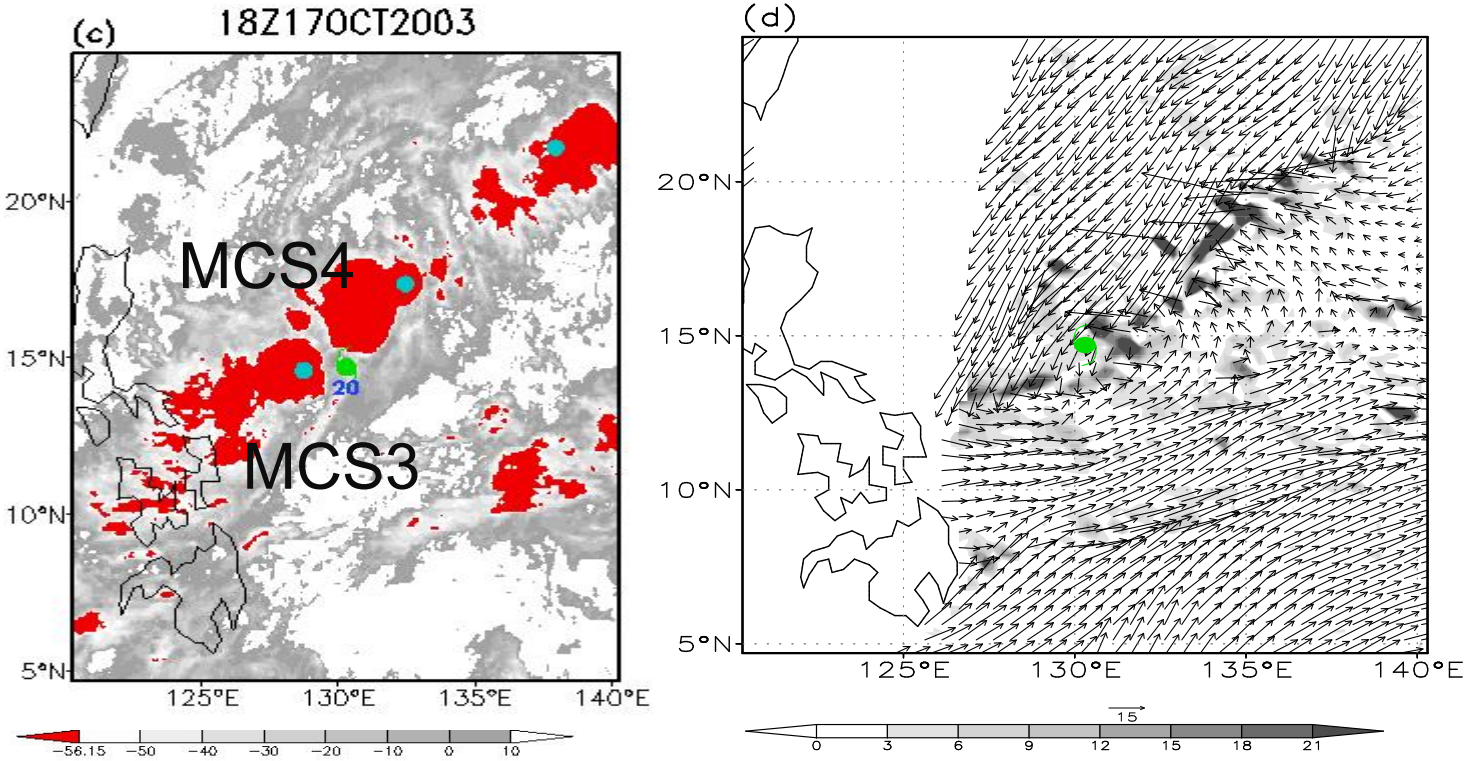
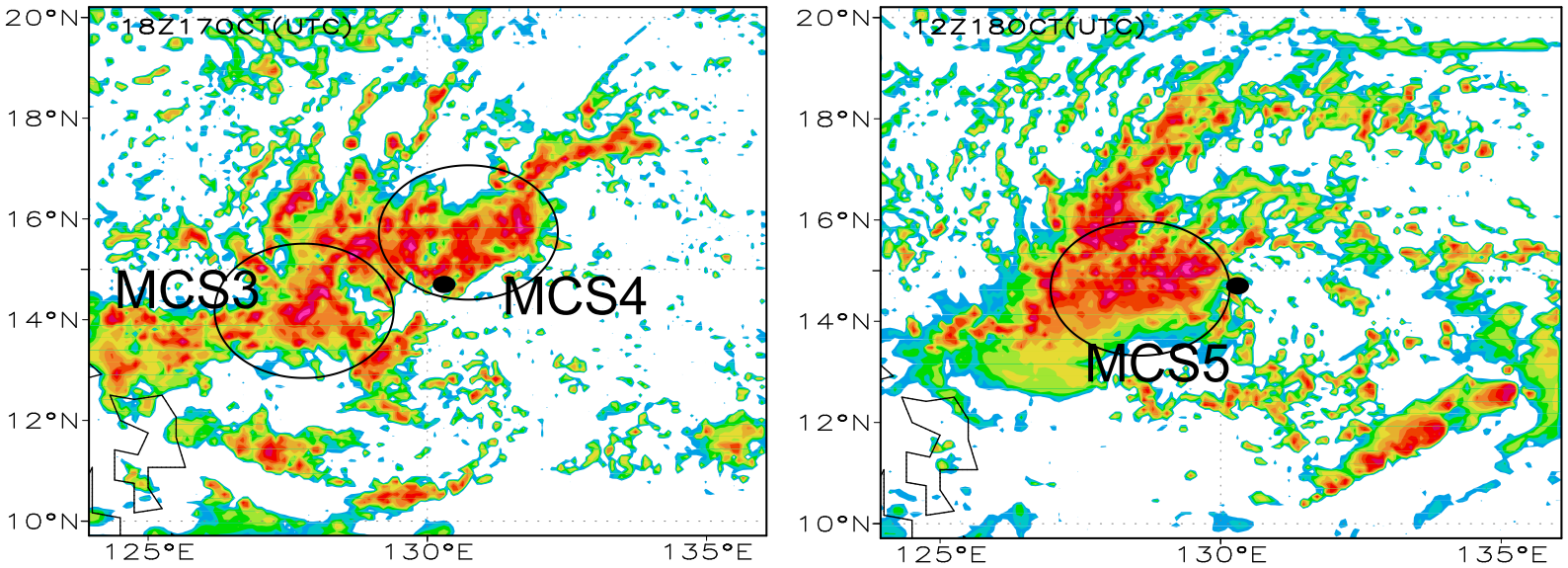


FIG. 2 Six-hourly IR1 satellite images from 1200 UTC 17 Oct 2003 to 1800 UTC 18 Oct 2003. The contour is TB of -75°C and the black dot is the best-track location of Ketsana's formation.



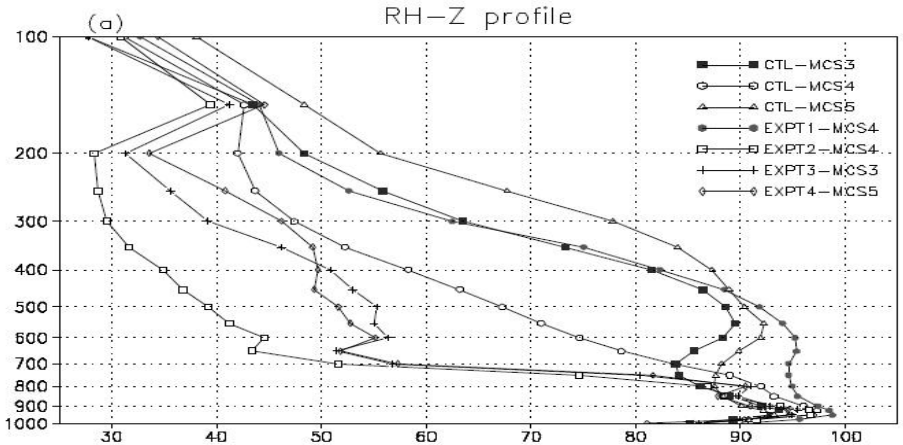
- **Once MCS occur, the low-level vorticity increase rapidly.**

Sensitivity Experiments



Simulated radar reflectivity

sensitivity experiments



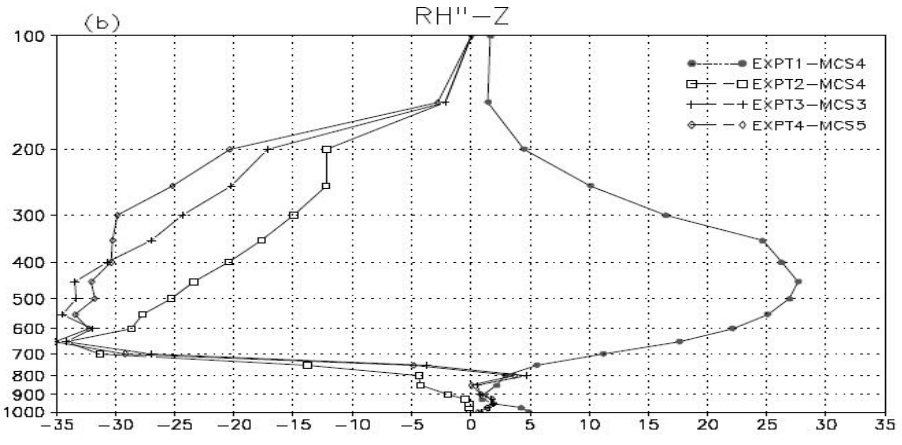


FIG .12 (a) Vertical variation with pressure (hPa) of the area-averaged simulated relative humidity (%) for the three MCSs in the control experiment and those in the four sensitivity experiments in the 27-km resolution domain. (b) As in (a) except for the difference of relative humidity in one of the sensitivity experiments from that in the control experiment.

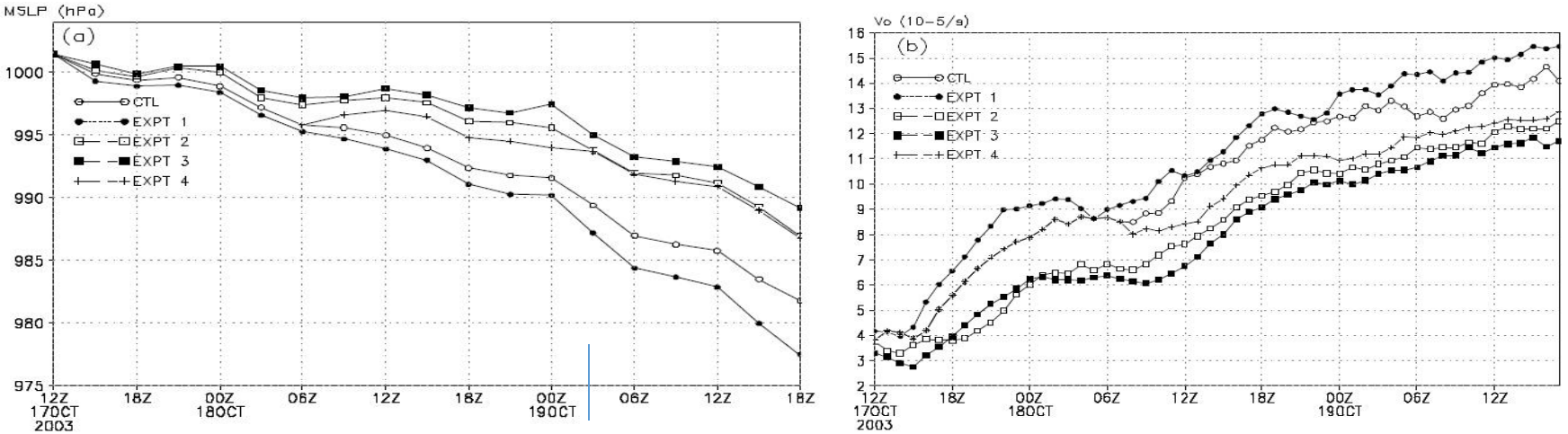


FIG.15 Times series of (a) the minimum sea-level pressure (unit: hPa) and (b) the area-averaged (127.5-132.5°E, 12.5-17.5°N) relative vorticity (unit: 10^{-5} s^{-1}) at model level σ=0.845 in the 9-km resolution domain for the control experiment (CTL) and the four sensitivity experiments (EXP 1, EXP 2, EXP 3, EXP 4).

- **Therefore，The MCS before formation seems to be quite critical in determining TC genesis and whether the system is formation or non-formation.**

OUTLINE

- Climate Background
- Large-scale Conditions Associated with TC Genesis
- The Features of MCSs Associated with TC Genesis
- TC Genesis Forecast
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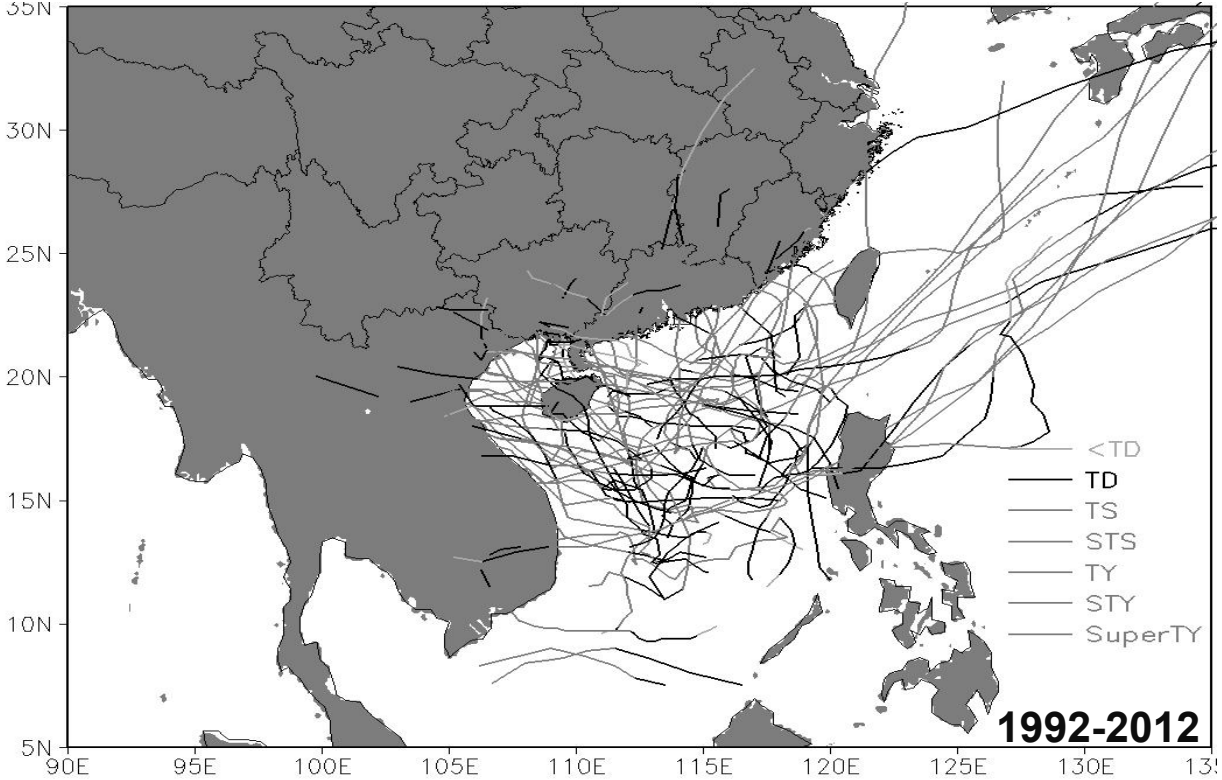
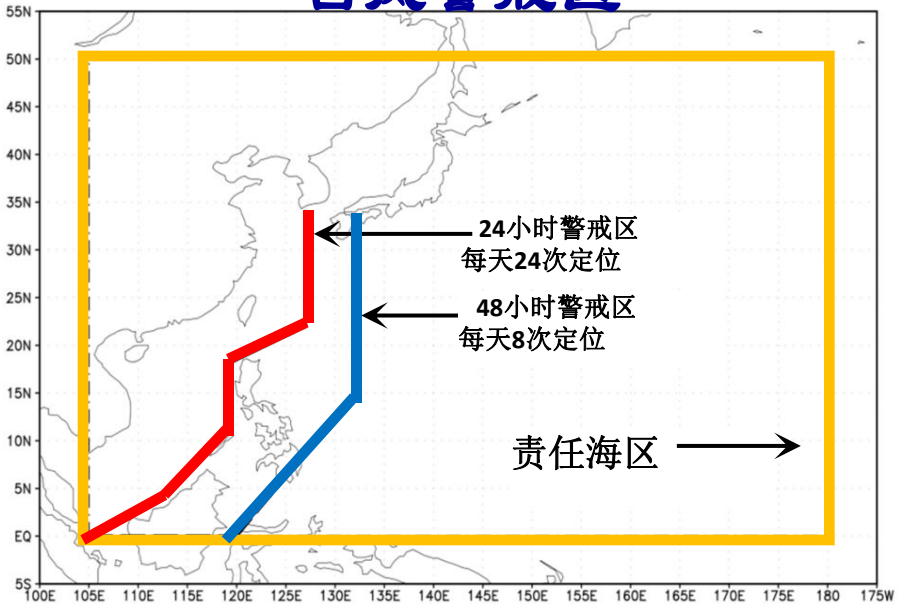
The Track of TCs in SCS



Once TC genesis in SCS, TC can intensify rapidly and quickly have effect on China's offshore, often causing the TC warning is not timely.
Therefore, the TC genesis forecast is necessary and important.

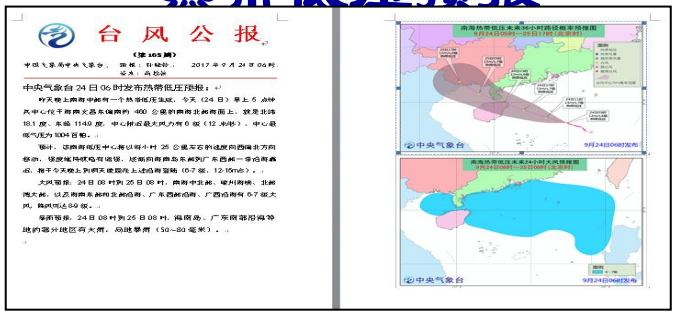
台风警戒区



GTS低压报

```
ZCZC 759
WTPQ20 BABJ 242100
SUBJECTIVE FORECAST
TD N 14 INITIAL TIME 242100 UTC
00HR 19.8N 108.9E 995HPA 16M/S
MOVE NNW 20KM/H
P+06HR 20.4N 108.0E 993HPA 18M/S
P+12HR 21.1N 107.2E 995HPA 15M/S
P+18HR 22.1N 106.2E 1005HPA 10M/S=
NNNN
```

热带低压预报


台 风 公 报

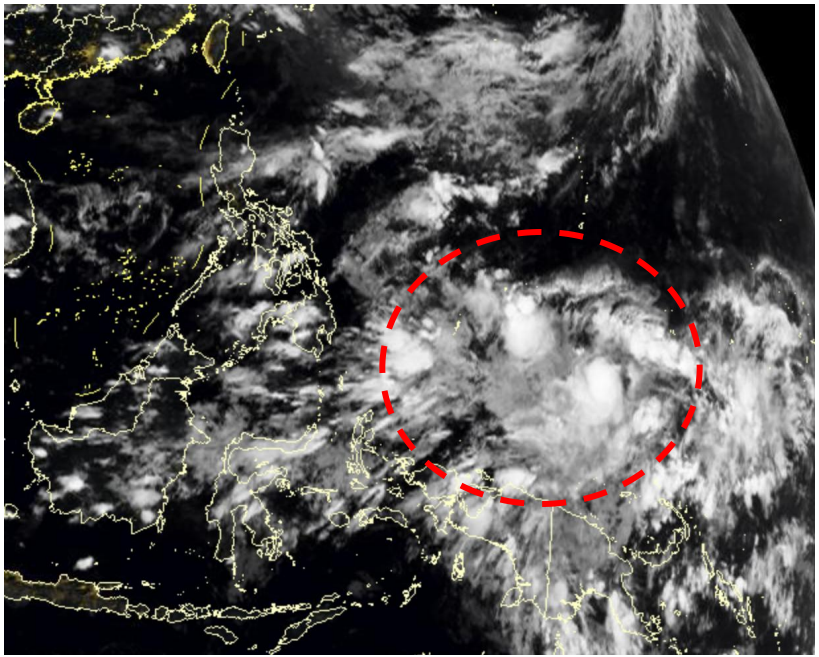
中央气象台 24 日 06 时发布热带低压预报：

中央气象台

中央气象台

Why TC genesis forecast is so difficulty?

Pre-existing sfc disturbanc



Why TC genesis forecast is so difficulty?

six seasonally averaged parameters about TC genesis (Gray 1968)

① the Coriolis parameter (f) Excludes belt between 5 - 8 deg either side of Equator.

② low-level relative vorticity (ζ_r)

③ vertical wind shear

④ ocean thermal energy, manifest as ocean temperatures greater than 26℃ to a depth of 60 metres (E)

⑤ the difference in equivalent potential temperature between the surface and 500hPa ($\Delta\theta_e$)

⑥ relative humidity in the mid-troposphere (RH)

dynamic

thermal

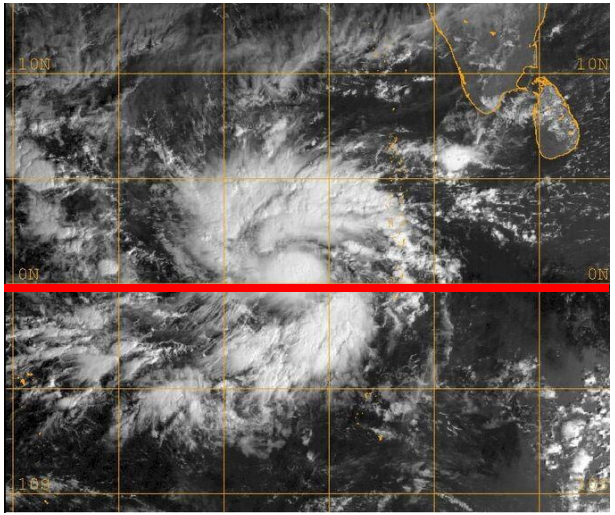
The above may be necessary conditions but not sufficient conditions. That is, even all above conditions can be met, the DB still can not develop into TC definitely. Necessary but not sufficient conditions!

Especially, we need to advance understanding of the physical differences between developing and non-developing systems, and can separate the developing from non developing DB.

The Rarest Typhoon

Typhoon Agni (2004) Formed over equator near Singapore

- Typhoon Agni formed closest to the equator (0.7 ^{o}N) in the world, a distance of about 80 kilometers from the equator, breaking the record for Typhoon Vamei.



Equator

Why TC genesis forecast is so difficulty?

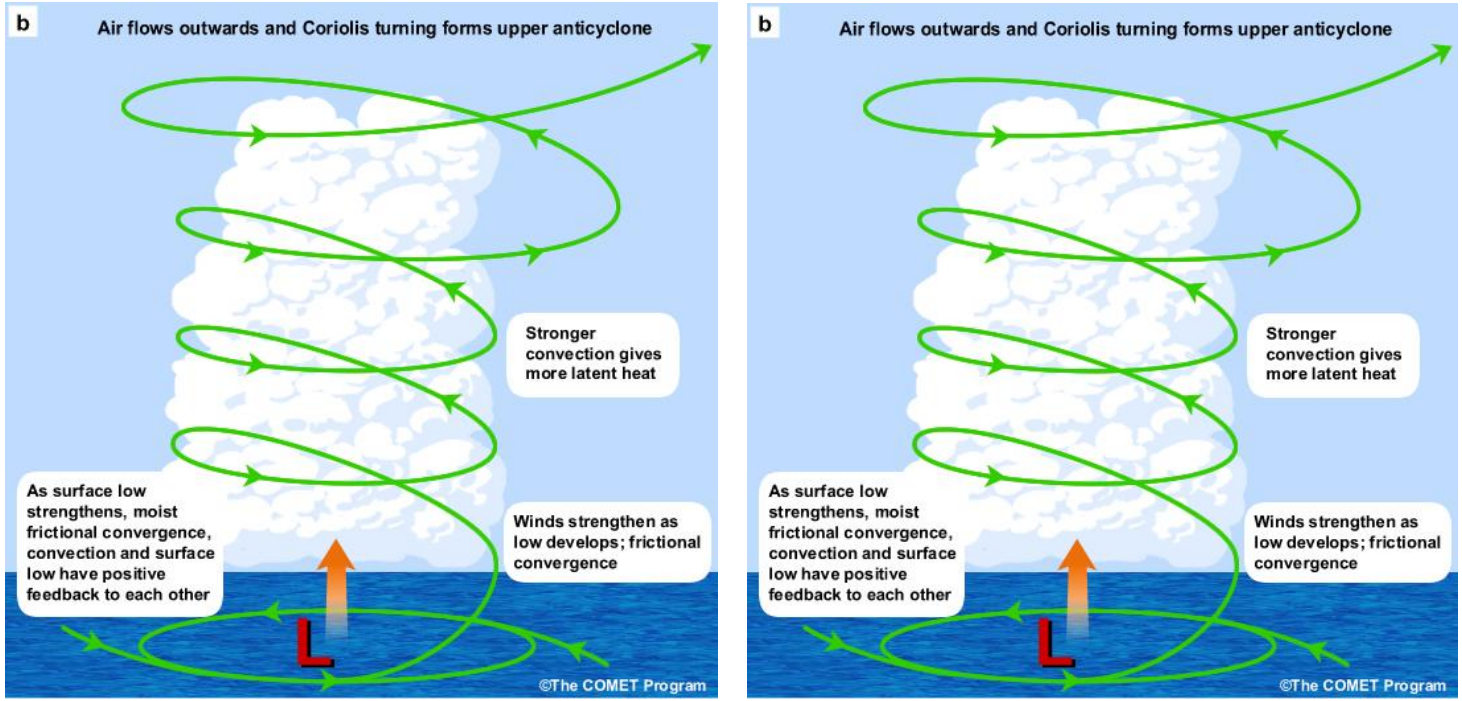
Theories of TC genesis

- CISK (Conditional Instability of the Second Kind, Charney and Eliassen (1964))
- WISHE (Wind-Induced Surface Heat Exchange, Emanuel (1986))
- Top-down (Ritchie and Holland (1997, 1999),Simpson et al. (1997))
- Bottom-up (Hendricks et al. (2004), Reasor et al. (2005),Montgomery et al. (2006) ,Tory et al. (2006), Lu, X., et al (2012))

There is no accepted TC genesis theory. Therefore，the processes that cause TC genesis can not be easily explained by the existing theories and has not been well understood.

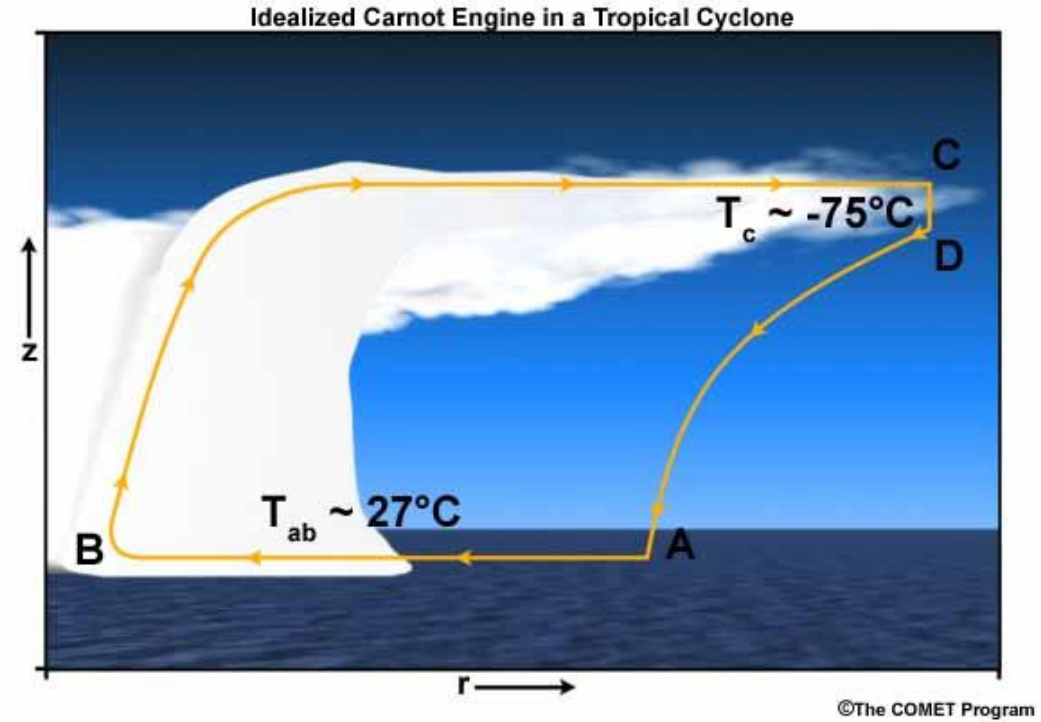
The existing theories can not be used in TC forecast quantitatively.

Schematic of CISK (Charney and Eliassen,1964)



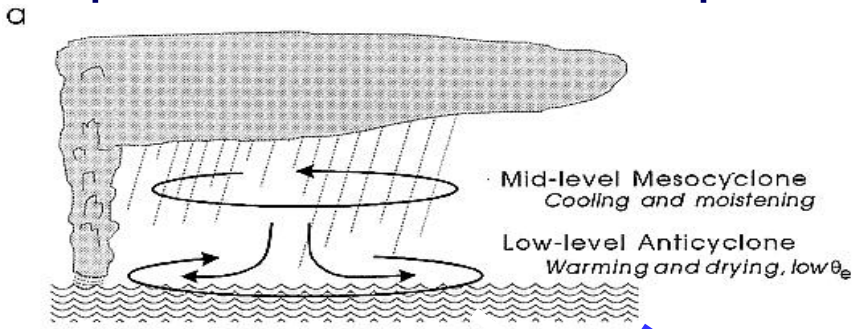
(a) given an incipient low-level cyclone with a moist boundary layer, frictional convergence of moisture, and forced ascent drive convection; (b) latent heating due to convection reduces surface pressure, strengthens the low-level cyclone, and enhances moisture convergence and convection in a positive feedback loop.

WISHE : A Carnot Cycle Theory of Potential Intensity (Kerry Emanuel， 1986）

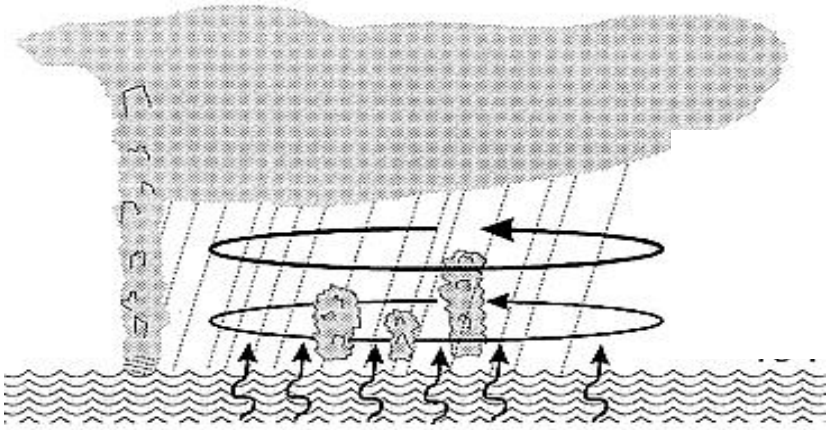


- Air in the atmospheric boundary layer flows in isothermally (AB),
- Rises adiabatically in the eyewall convection (BC),
- Diverges isothermally near the tropopause in the outflow anticyclone(CD).
- To close the circuit, this air must sink far from the storm (DA)

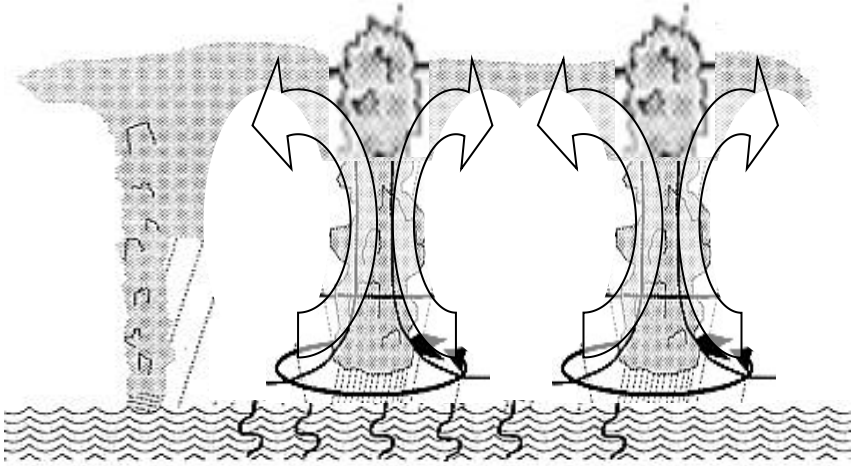
Top-Down vs. Bottom-Up

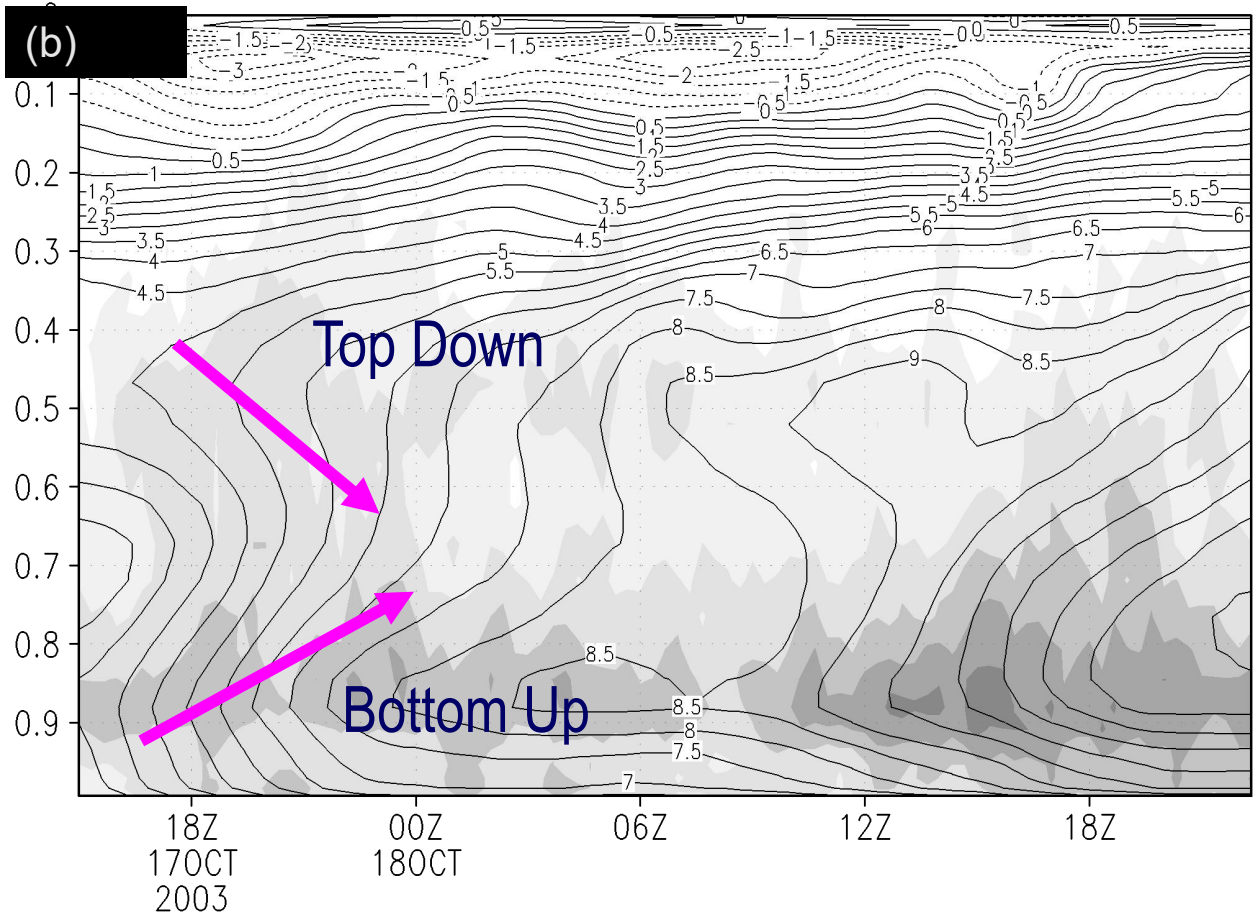


Top Down



Bottom Up

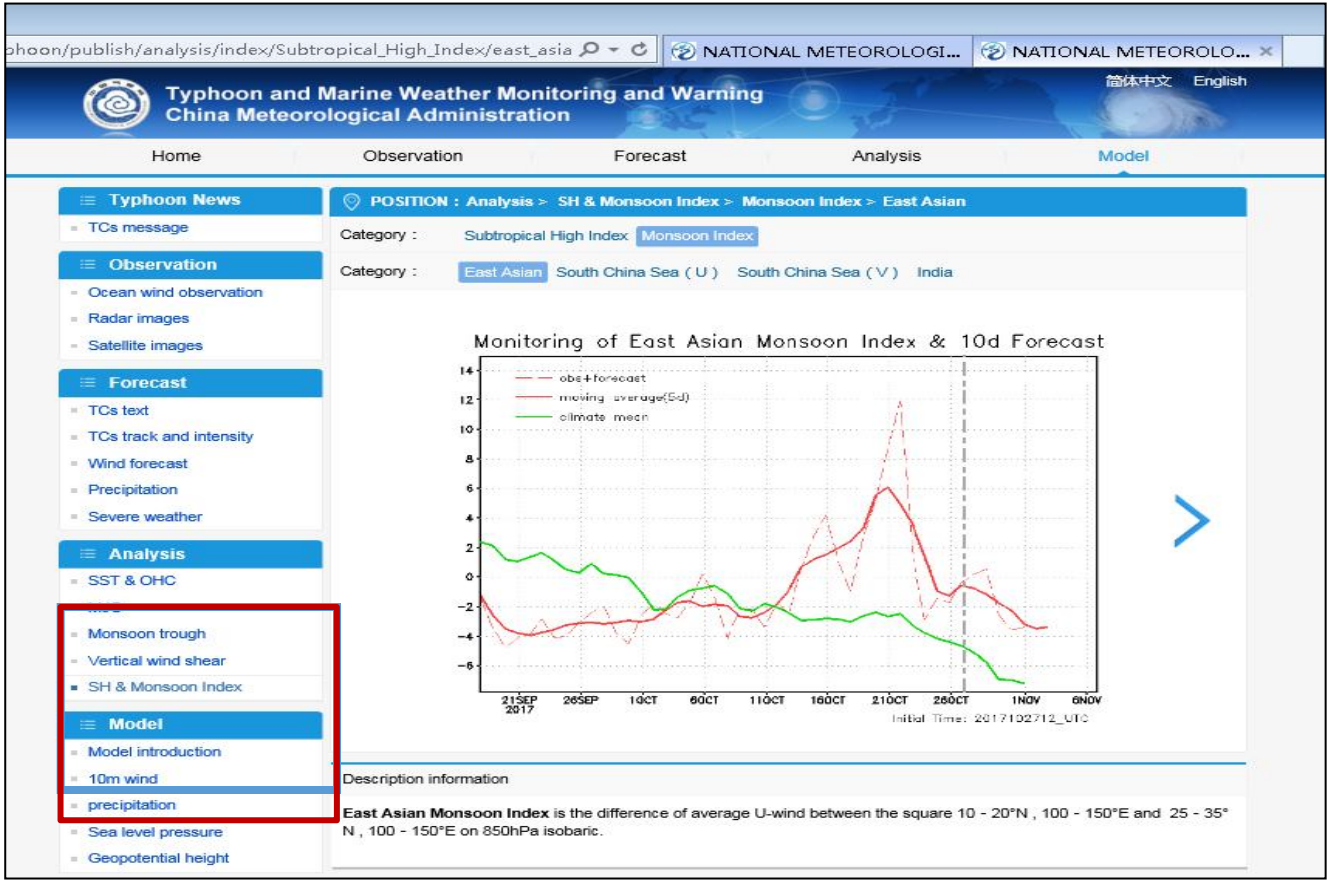



(b)
Top Down
Bottom Up
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
18Z
17OCT
2003
00Z
18OCT
06Z
12Z
18Z

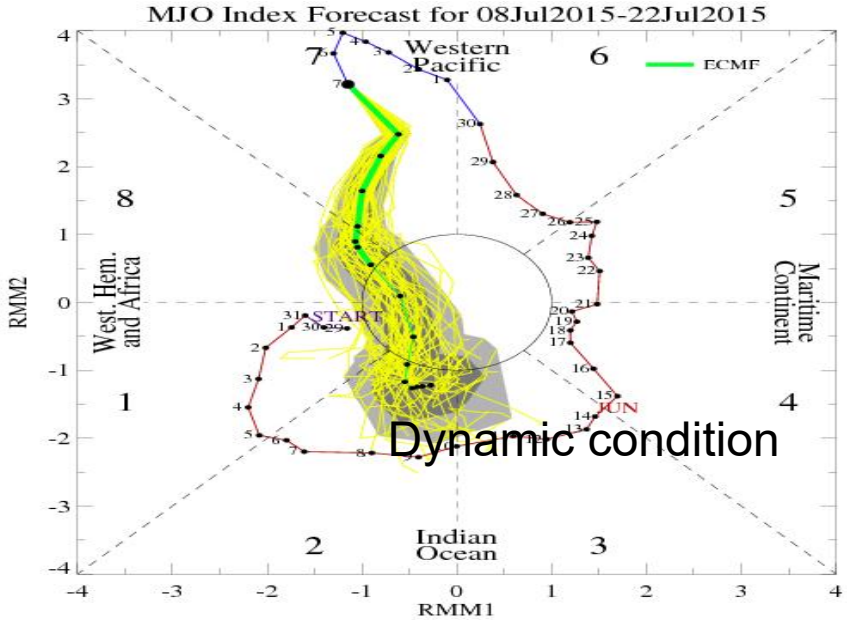
TC Formation Research

Tropical cyclogenesis has been a popular atmospheric science research topic in the past few decades, but it remains the least understood phase of the tropical cyclone life cycle（Emanuel，2005）.

Monitoring TC genesis

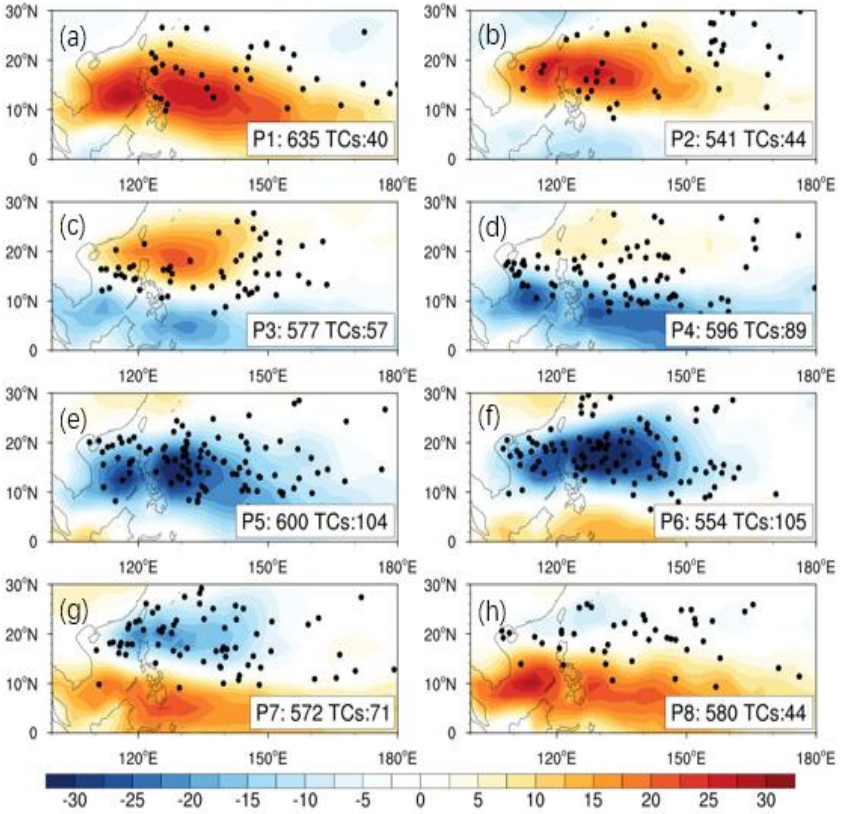


1： Intraseasonal variability （MJO)



- **Conceptual model showing idealized phases of MJO progression.**
- **Phases 6 and 7 are most active phases for the Western Pacific.**
- Global models handle the MJO much more accurately now, and thus the forecaster can add value to the deterministic model output.

MJO and TC genesis



- **The MJO exert the strong impact on TC genesis in the WNP**

MJO and TC genesis

- Active convection associated with MJO leads to increase in tropical cyclogenesis.
- The number of TC genesis events is most enhanced in the western North Pacific when the MJO is in phases of 5,6 and 7,with significant re-ductions in phases 3–4.

TABLE 6. As in Table 2, but for the northwest Pacific Ocean. A total of 351 northwest Pacific Ocean basin TCs underwent at least one 24-h RI period of 30+ kt during the period from 1979 to 2011.

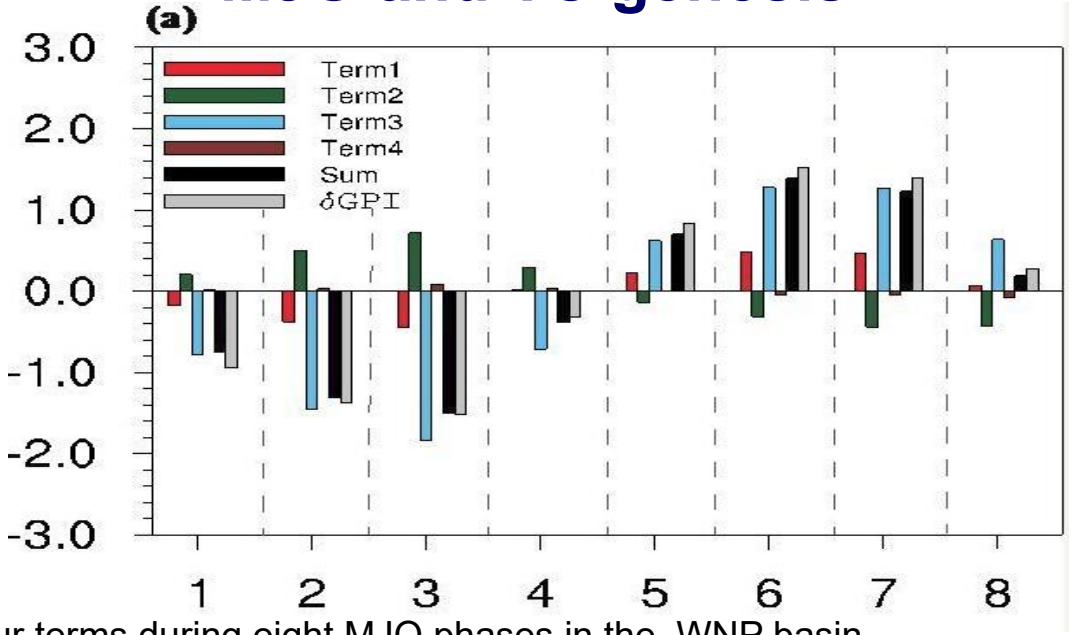
Phase	NS	H	MH	Basinwide ACE (%)	RI 24-h periods	RI chance (%)
1	9.5	7.3	3.8	12	19.2	49
2	*8.4*	6.3	3.2	9	16.8	**57**
3	*6.1*	*3.5*	*1.7*	*6*	*12.1*	43
4	9.0	*4.7*	2.9	*8*	15.3	35
5	**15.7**	9.3	4.6	14	23.5	36
6	**18.0**	**11.8**	4.8	**17**	27.6	34
7	**15.2**	**11.1**	**7.0**	**21**	**33.5**	50
8	9.5	6.6	3.7	12	22.6	**55**
Phase 1–8 avg	11.6	7.7	3.9	12	21.2	43

NS: named storms
H: hurricanes
MH: major hurricanes

NS, H and MH during each phase of MJO are extracted when the amplitude of MJO is large (WH index is greater than one).

Klotzbach(2013), The Madden–Julian Oscillation's Impacts on Worldwide Tropical Cyclone Activity

MJO and TC genesis



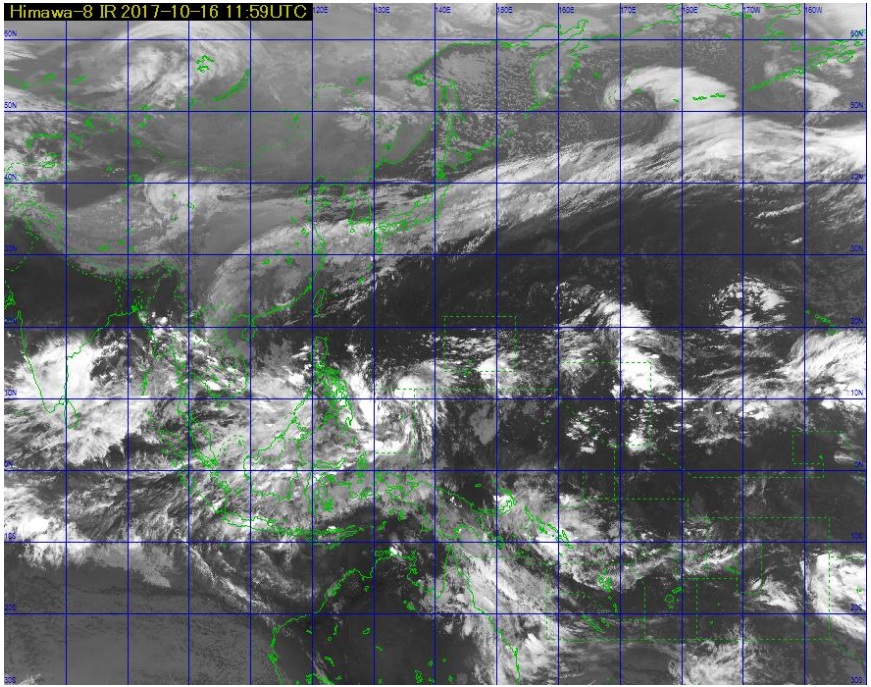
The sum of the four terms during eight MJO phases in the WNP basin.

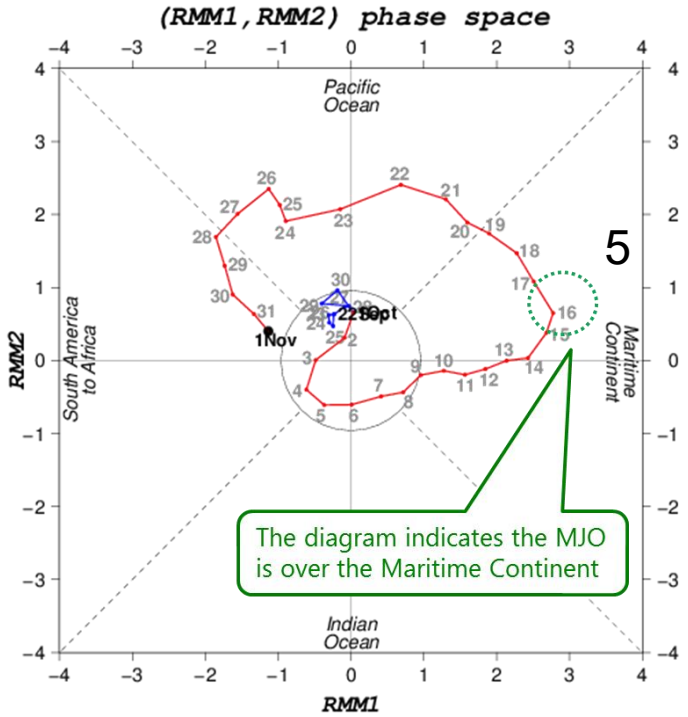
Term1 represents vorticity (red), Term2 represents vertical wind shear (green), Term3 represents relative humidity (blue), Term4 represents potential intensity (brown), Sum represents the sum of the four terms, and δGPI represents the anomalous GPI from observation (Zhao Chen, Li Tim.,2018)

- **The TC genesis are more active in Phase 5-7, especially in Phase 6 and 7.**

Satellite image for active MJO phase in WNP

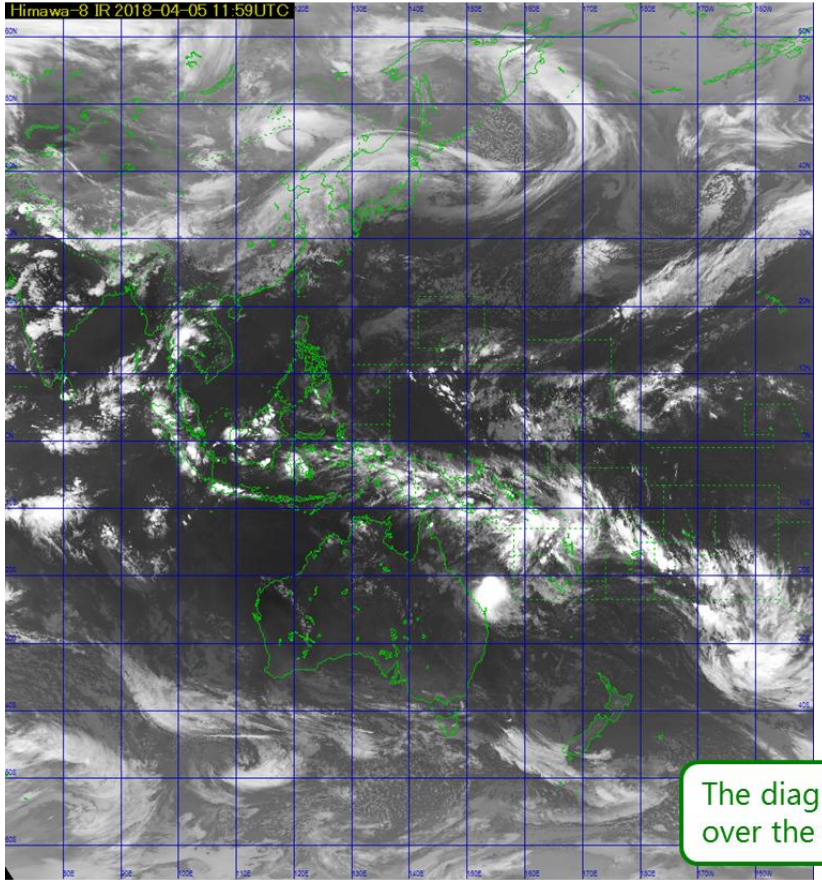
12UTC OCT. 16, 2017

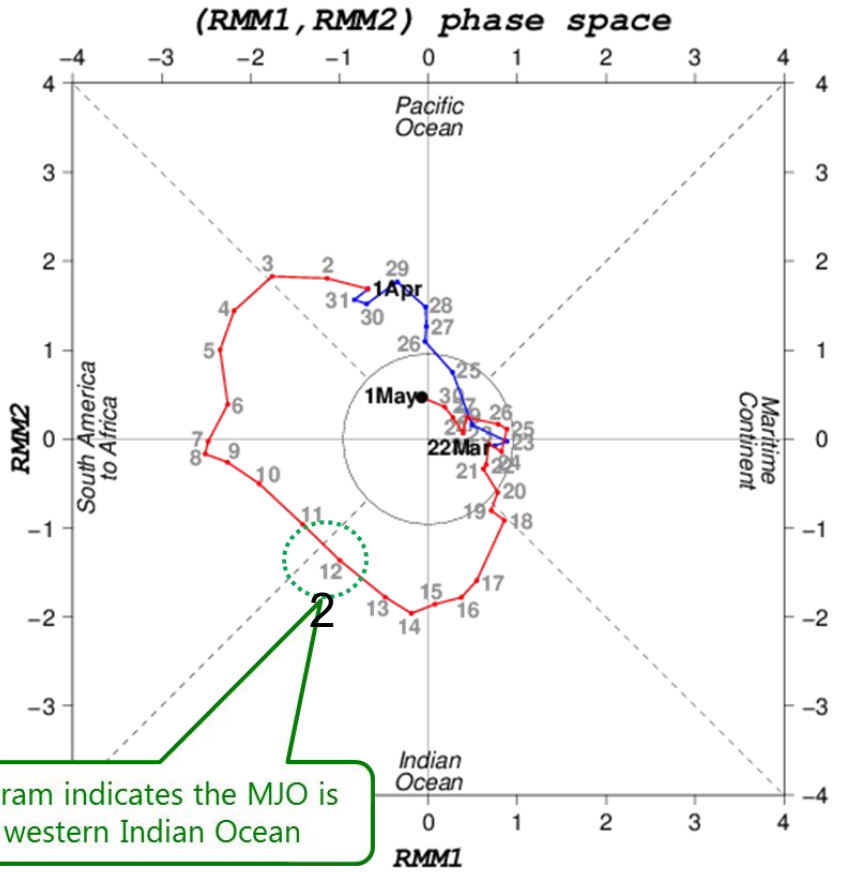




Satellite image for inactive MJO phase in WNP

12UTC APR. 05, 2018

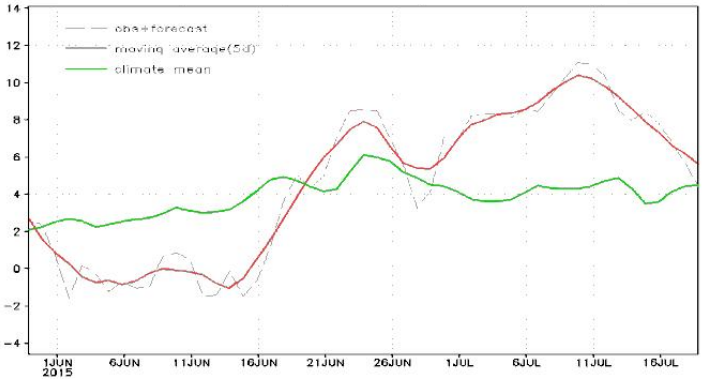




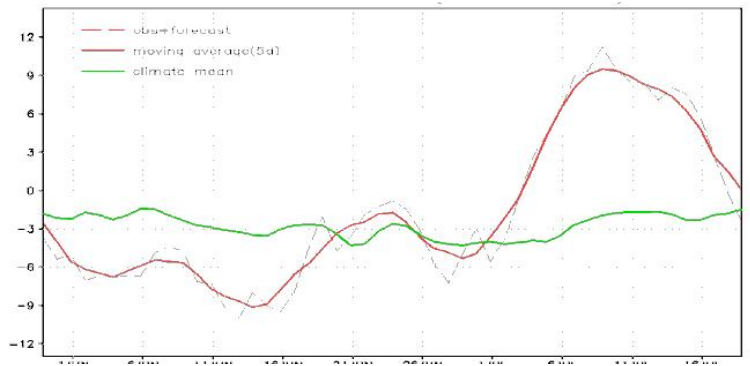
The diagram indicates the MJO is over the western Indian Ocean

2： Large-Scale Circulations

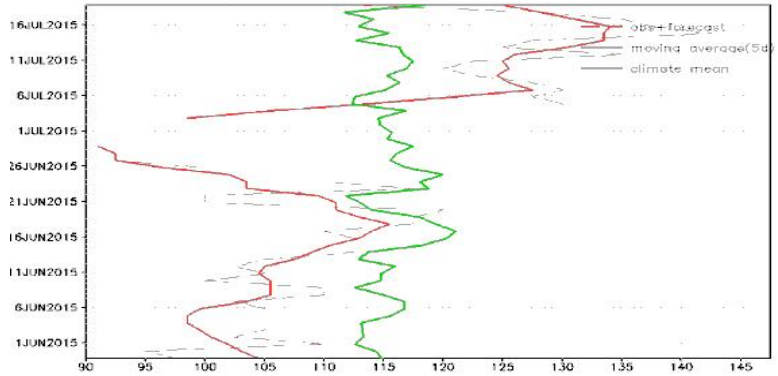
Monsson index in SCS



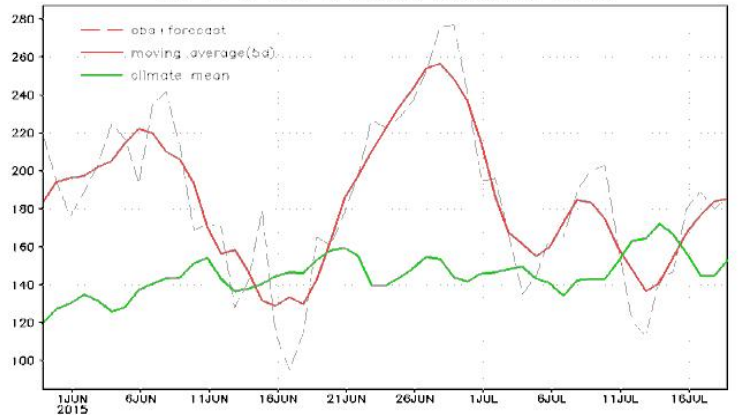
Monsson index in East Asian



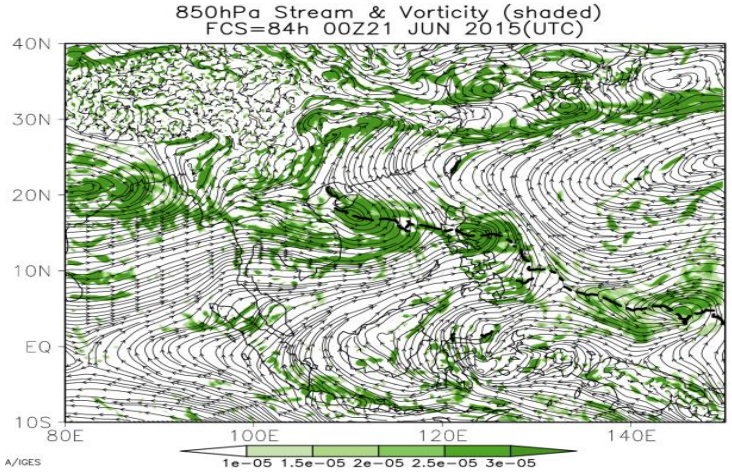
Western ridge of Subtropical High

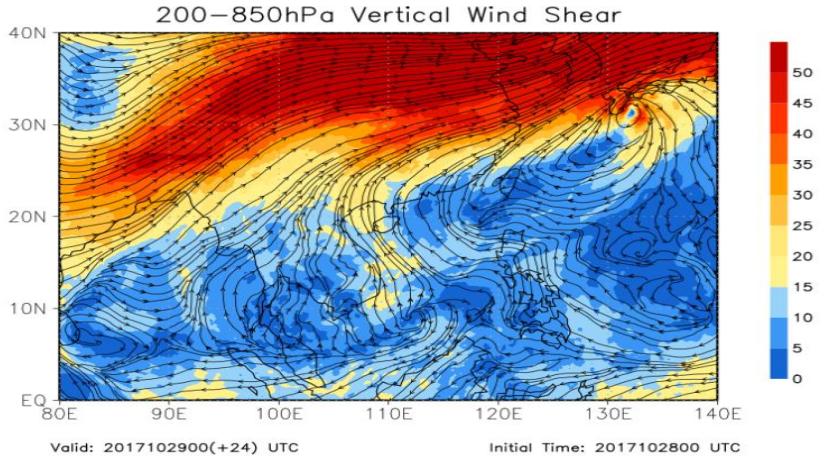


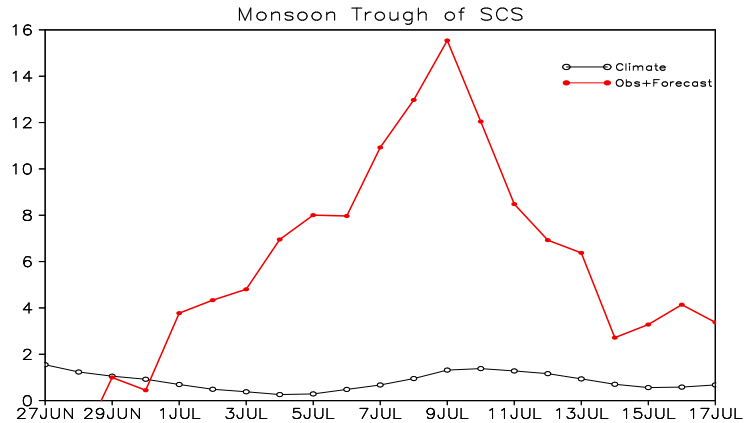
Area of Subtropical High

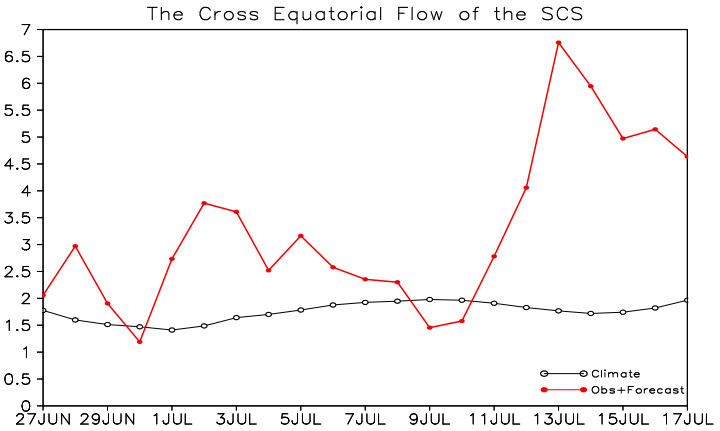


Monsoon trough and Vertical wind shear (Dynamic conditions)；



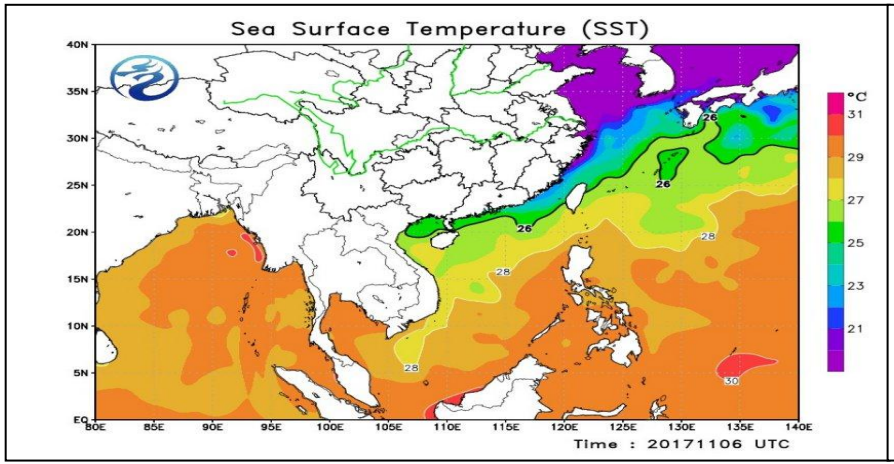


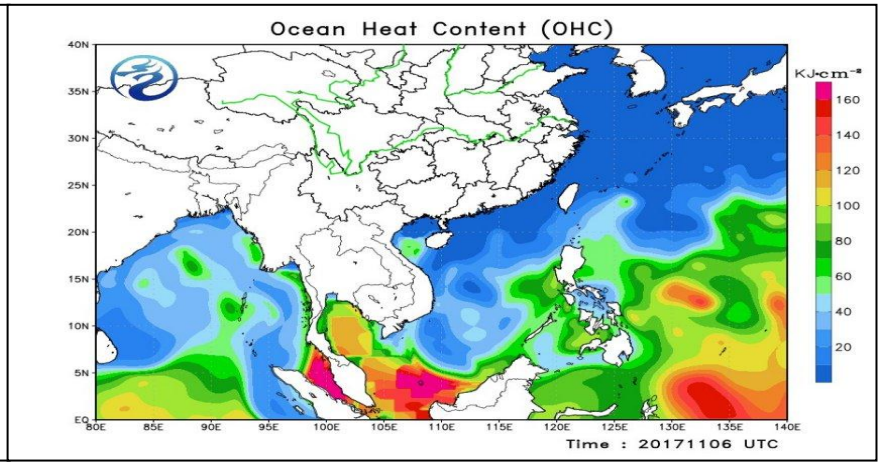




3：Ocean heat Condition

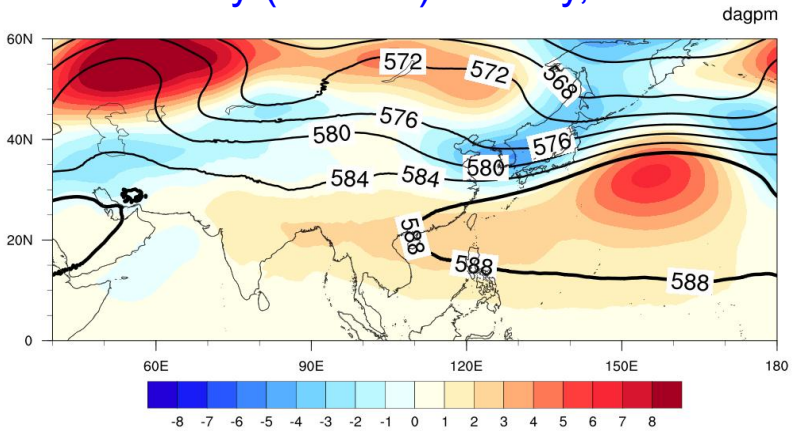
第三类	产品
海洋热力状况（3） 基于美国海军“全球海洋资料同化试验”（GODAE）项目	海表温度SST
	热容量OHC(Ocean Heat Content)
	26度暖水深度Depth of 26 ˚C



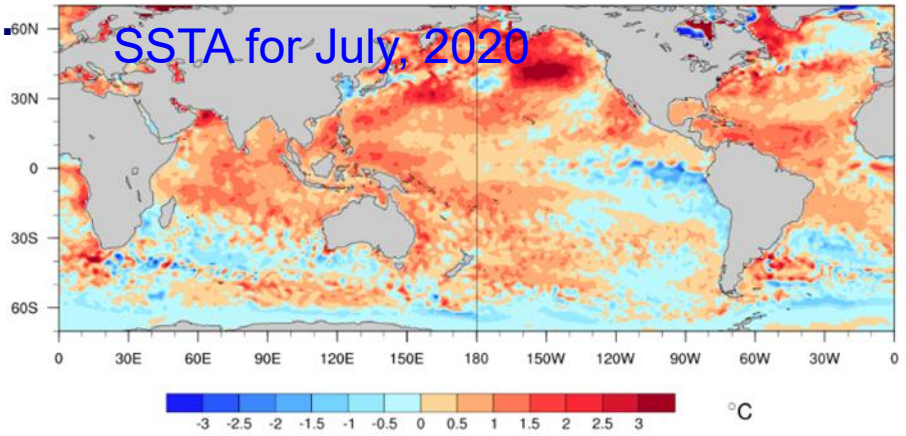


No TC genesis over SCS-NWP in July, 2020.

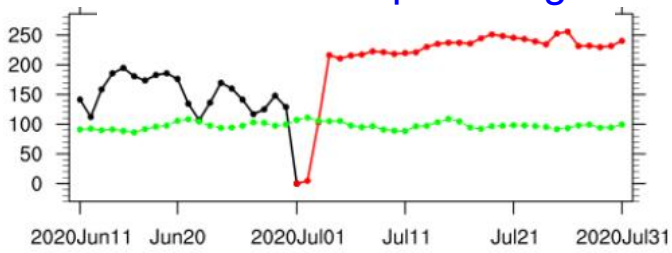
500hPa Geopotential height (contour) and its anomaly (shaded) for July, 2020

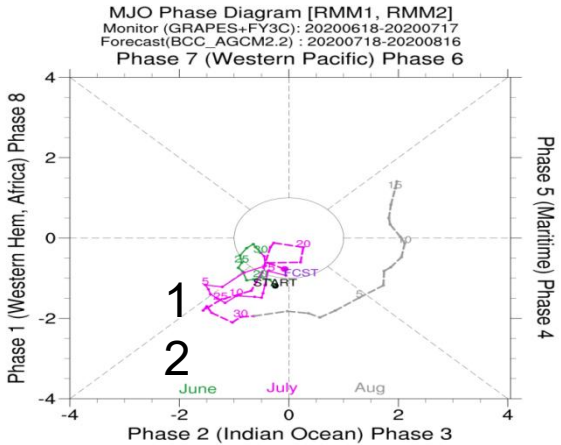


SSTA for July, 2020

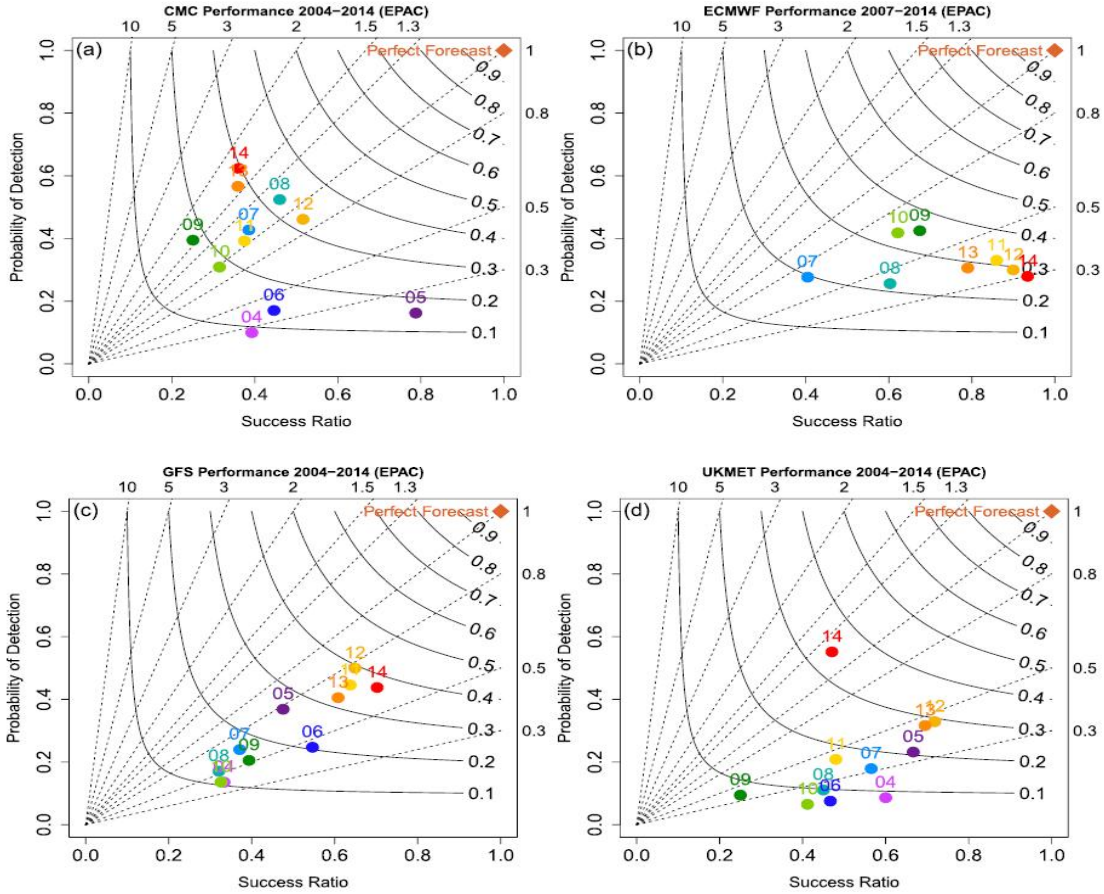


Area of Subtropical High



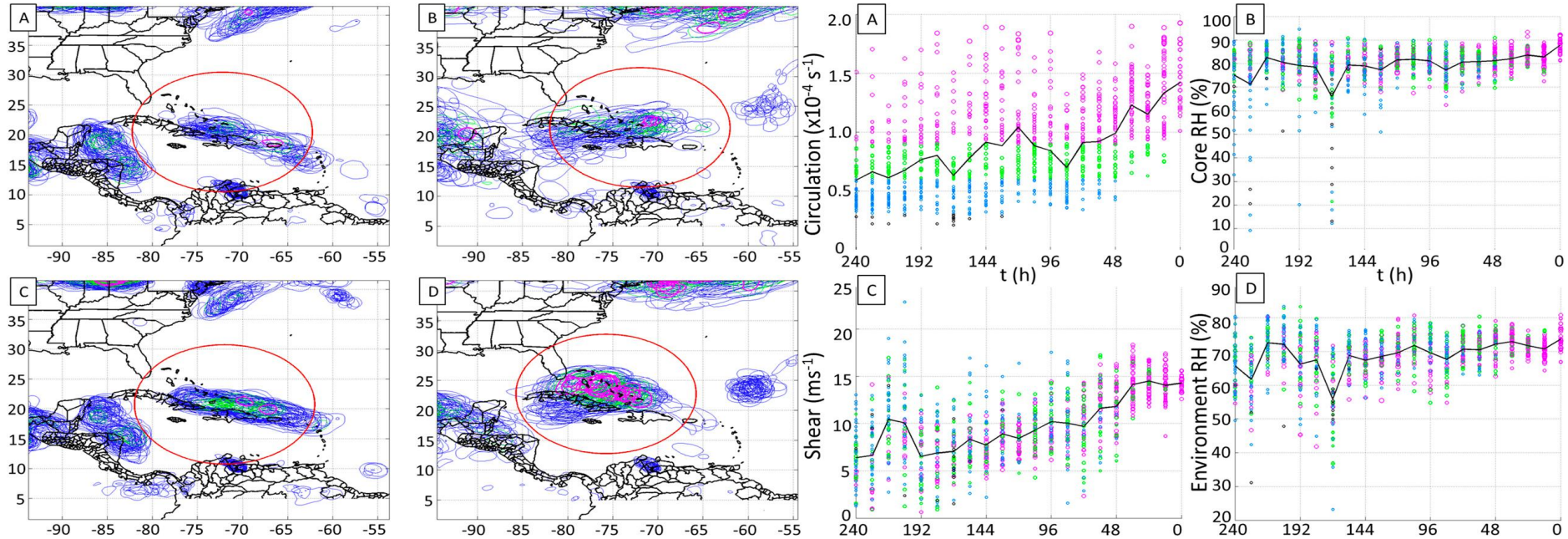


The subtropical high is abnormally stronger, and its area is about twice of the climate average. This is unfadable for TC genesis.



Halperin et al. (2016)

- **The progress of global models improve of tropical cyclone genesis forecast.**



Komaromi and Majumdar (2015)

- **Recent upgrades to the ECMWF have probably improved its ability to TC genesis forecast.**
- **The ensemble forecast can predict the some TC genesis one week before formation.**

Therefore, Global models, especially the ECMWF, and GFS, along with their ensembles can provide the primary tool for predicting TC genesis.

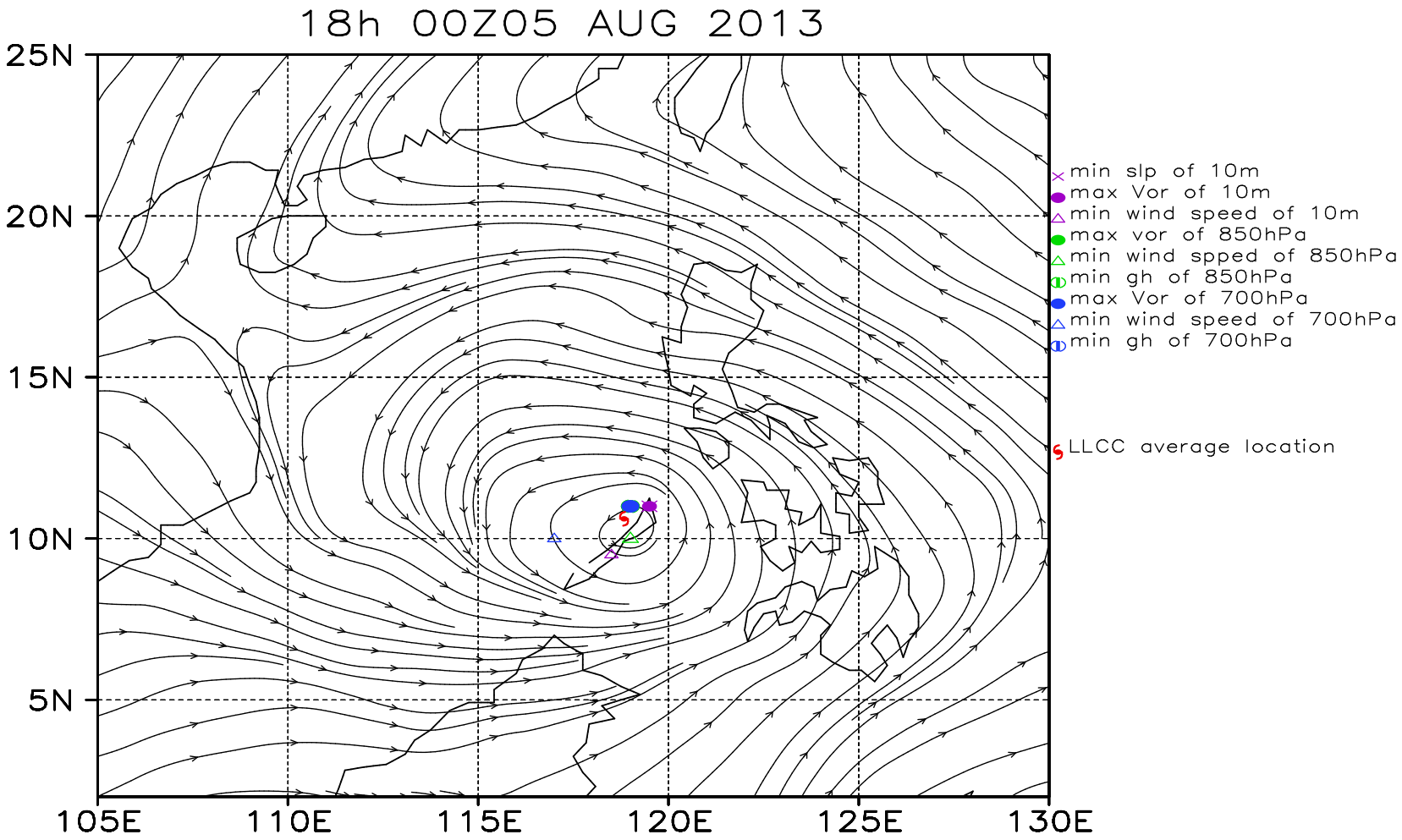
TC Genesis Probability Basing on Ensemble Prediction System

Key: How to define TC genesis in the global model?

The First step: to refine a reasonable centers of the lows

- 1） mslp
- 2） maximum vorticity (850/700hPa/10m)
- 3) minimum geopotential height (700 hPa, 850 hPa)
- 4） minimum wind speed(850/700hPa/10m)

To average the nine locations (latitudes and longitudes) and get a reasonable centers of the low (usually very weak).

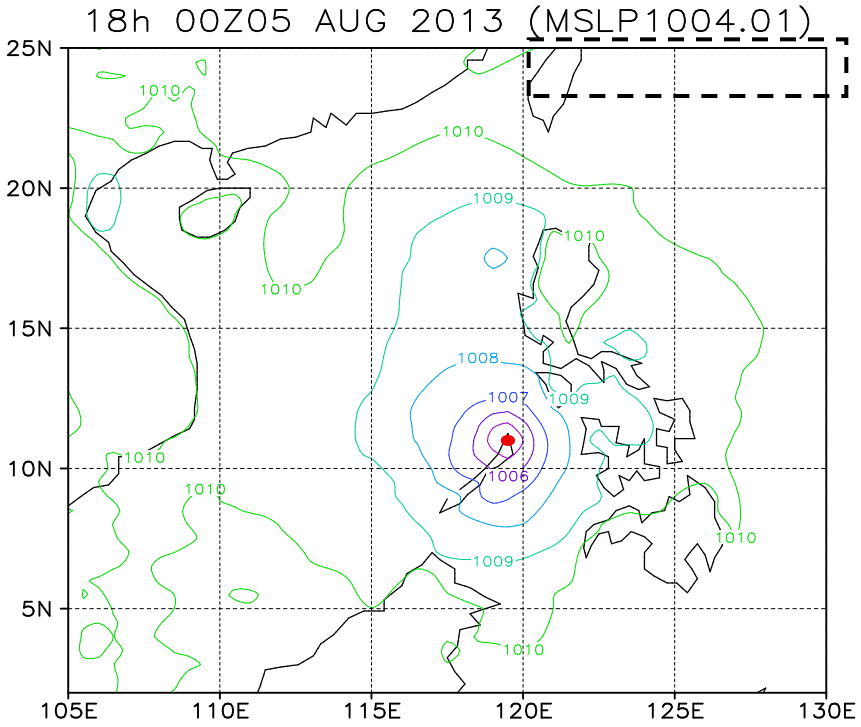

18h 00Z05 AUG 2013
25N
20N
15N
10N
5N
105E
110E
115E
120E
125E
130E
min slp of 10m
max Vor of 10m
min wind speed of 10m
max vor of 850hPa
min wind spped of 850hPa
min gh of 850hPa
max Vor of 700hPa
min wind speed of 700hPa
min gh of 700hPa
LLCC average location

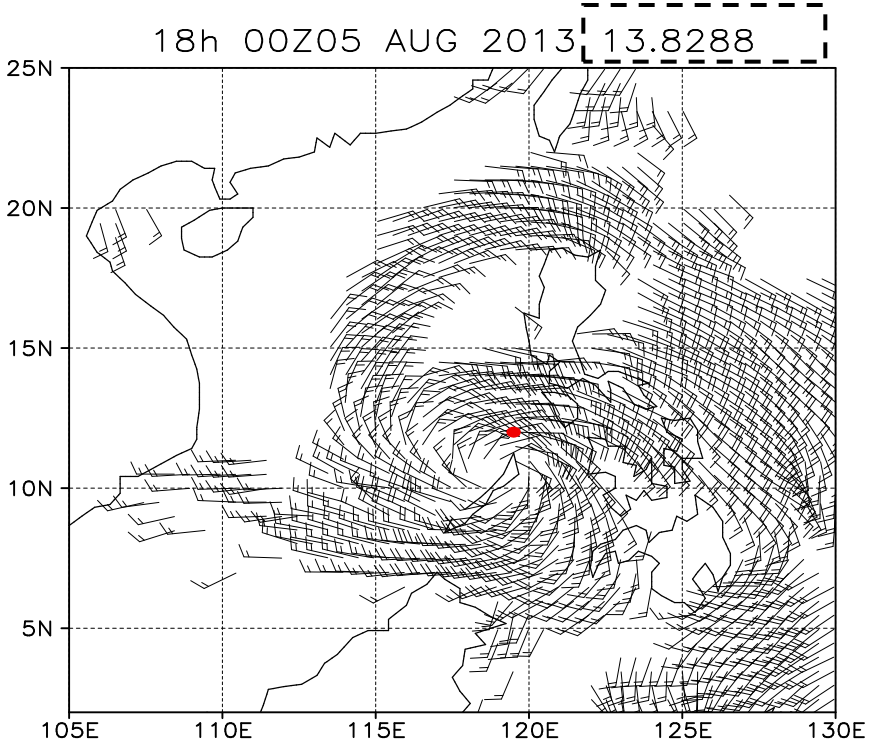
The Second step: to filter the lows

-- to confirm whether the lows are tropical cyclones basing on the following criteria

- 1) Closed SLP contour (1hPa interval, with mslp<1005hPa)
- 2) Surface maximum wind speed (10m) ⩾ 8m/s
- 3) 850hPa maximum vorticity ⩾10^{-4} 1/s (within a disk of radius 200km)
- 4) 300-500hPa temperature anomaly ⩾0.5℃ (warm core)

  (the averaged temperature (averaged within a disk of radius 100km) exceeding environmental temperature (averaged within a disk of radius 1000km).
- 5) The life time>24 hours

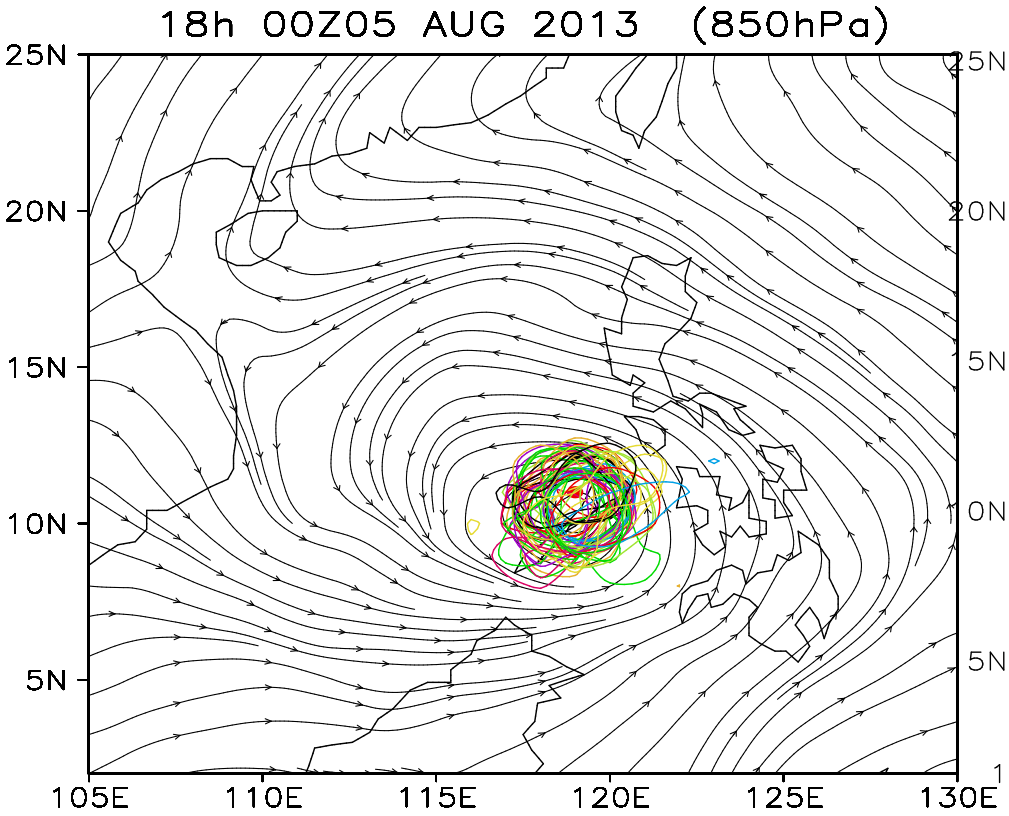


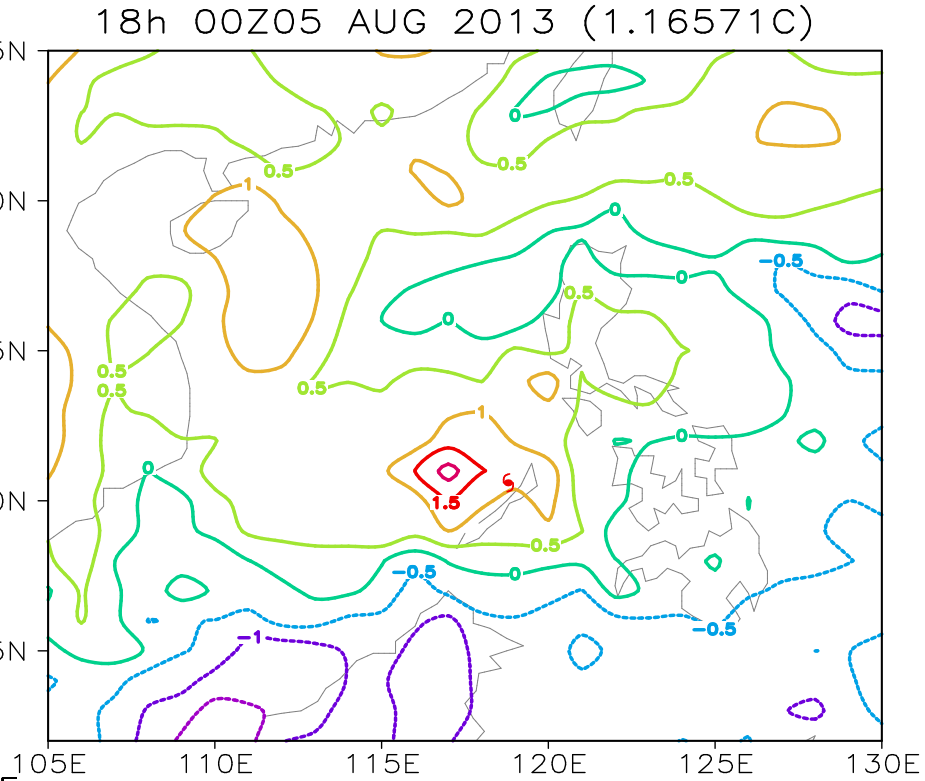


Closed SLP (<1010hPa)

The red dot is the location of mslp.

The maximum wind speed (10m) >8m/s, **The red dot is the location of The maximum wind speed .**





850hPa maximum vorticity **≥10-4 1/s (**within a disk of radius 200km).

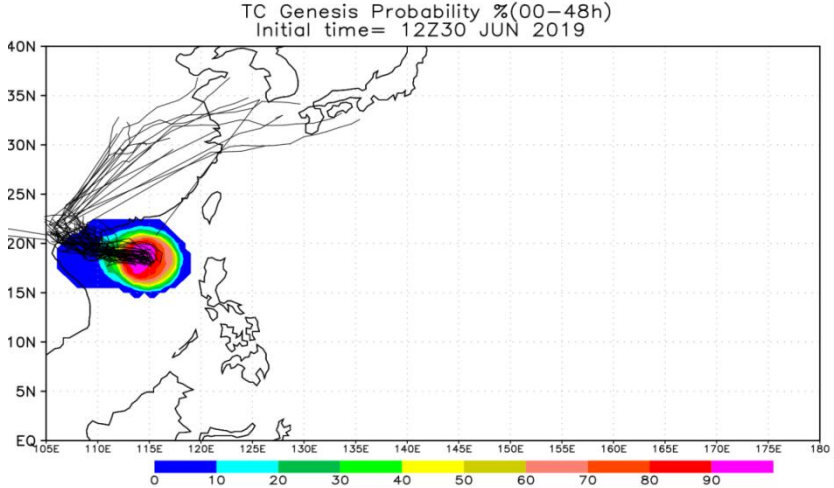
300-500hPa temperature anomaly **≥0.5℃ (warm core)**.

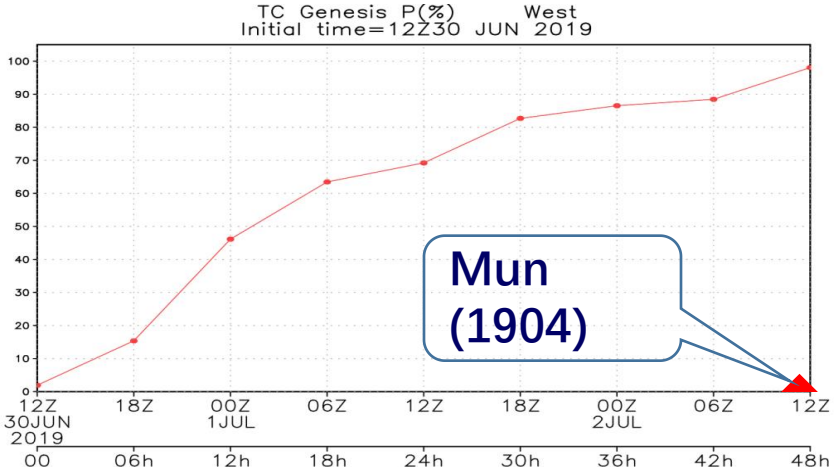
The life time must be over 24 hours.

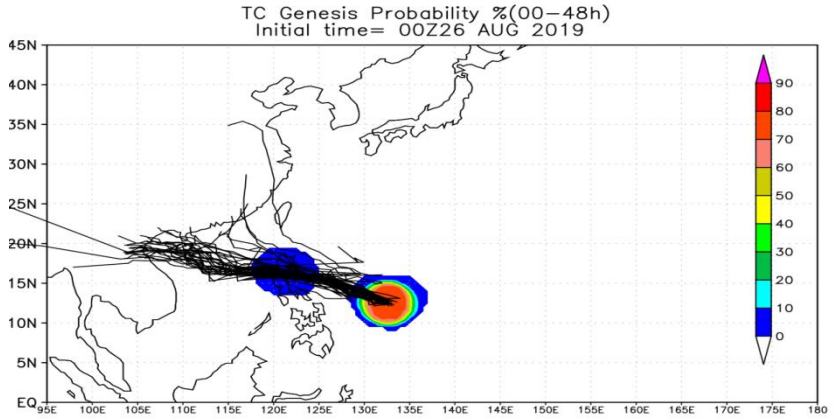
The Third step: to calculate TC genesis probability

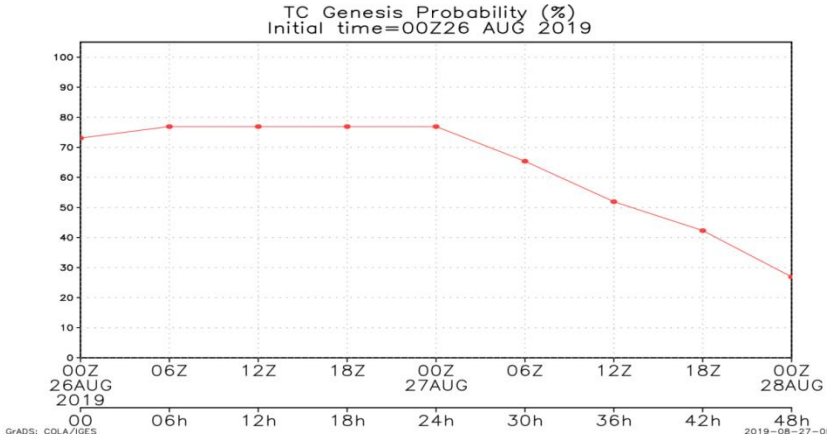
- 1） For each member of EPS, decide whether there is a TC genesis.
- 2） Calculate fraction of members indicating genesis within a 350 km radius of each grid point .
- 3) Provide the TC genesis probability products.

Typhoon Forecasting : TC Genesis Probability

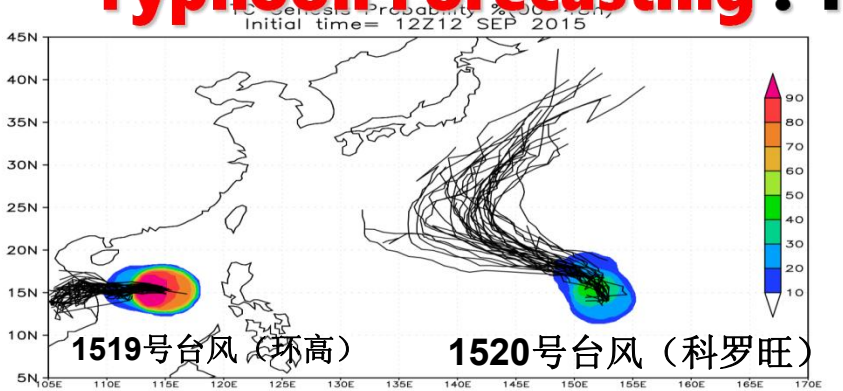


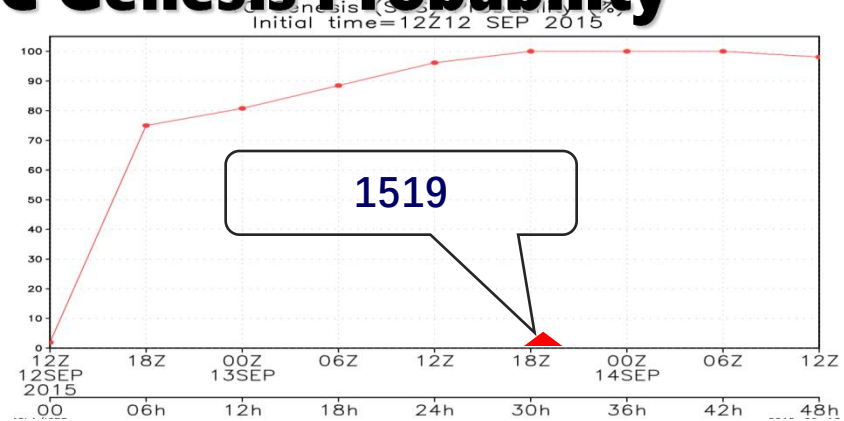


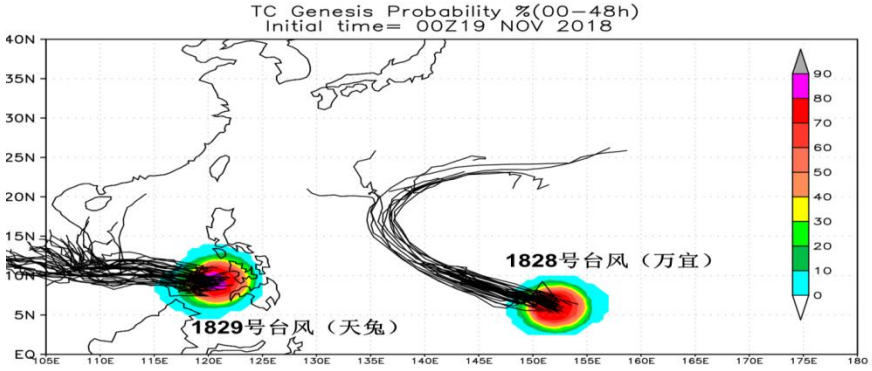




Typhoon Forecasting : TC Genesis Probability

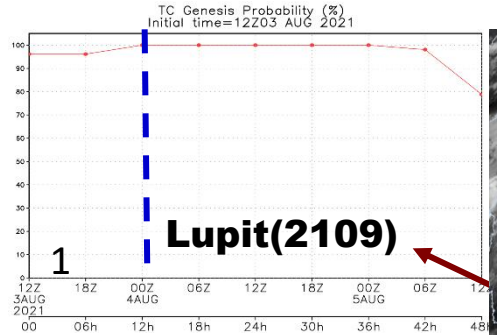


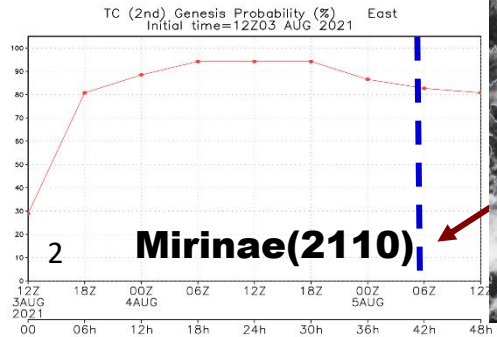


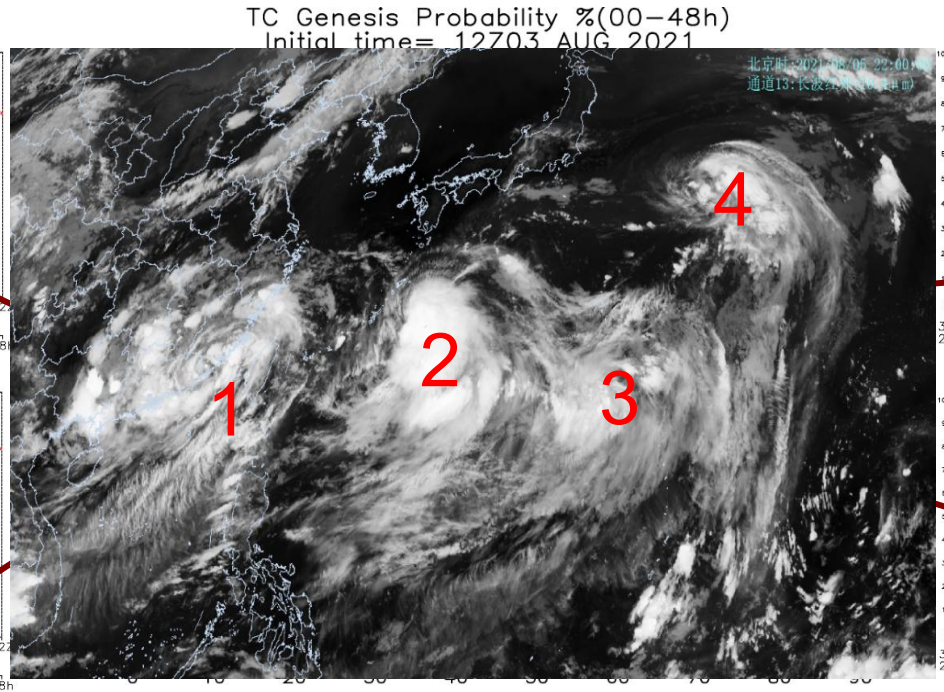


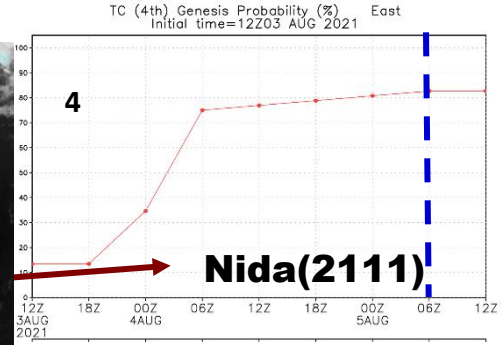
The products can provide more useful guidance for TC genesis forecast.

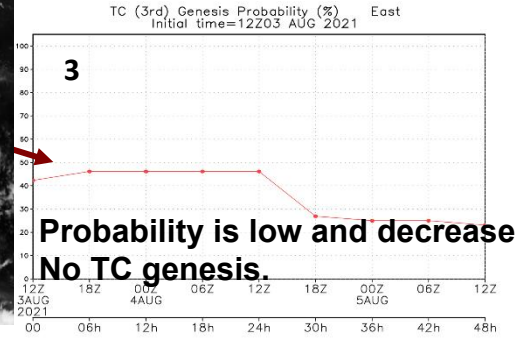
Typhoon Forecasting : TC Genesis Probability







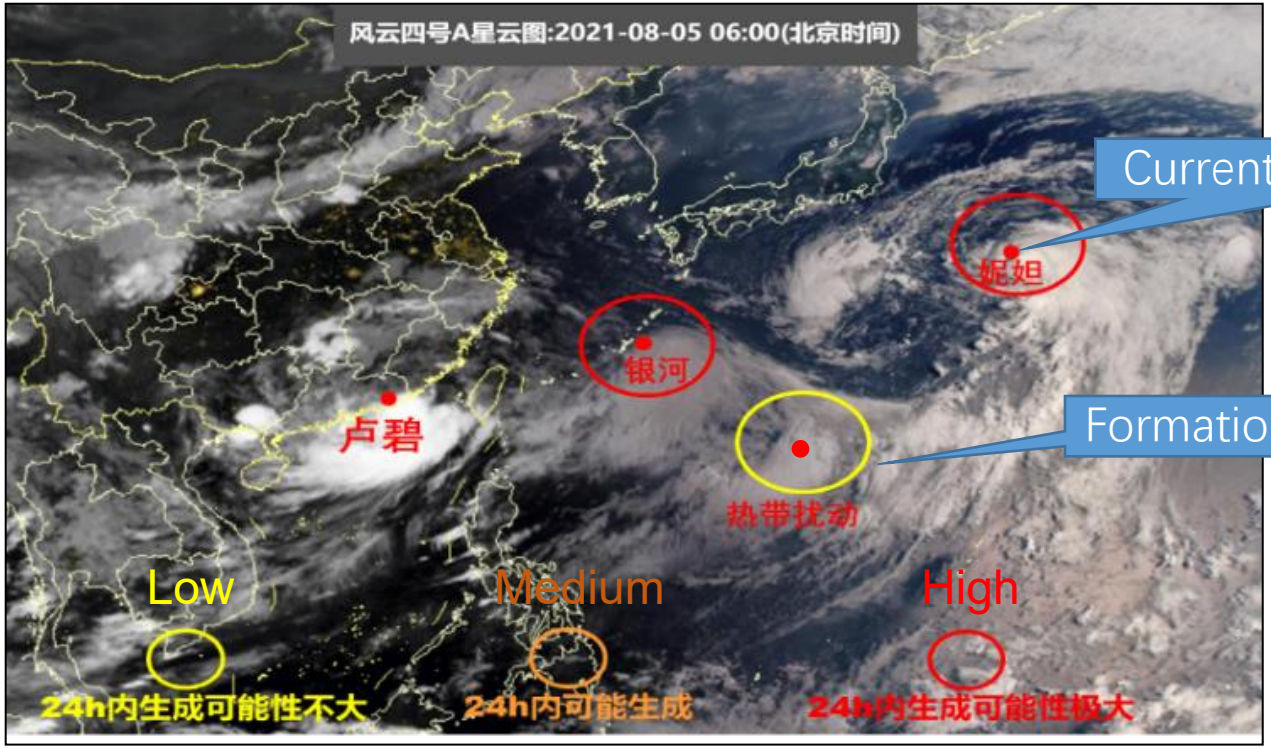




The TC genesis products can provide more valueful information for TC genesis forecast, with high detection rate (above 85%).

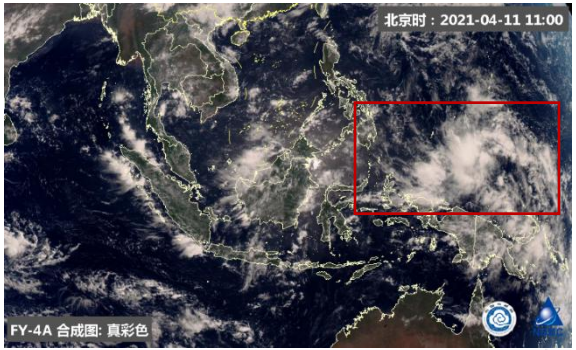
Typhoon Forecasting : TC Genesis Probability

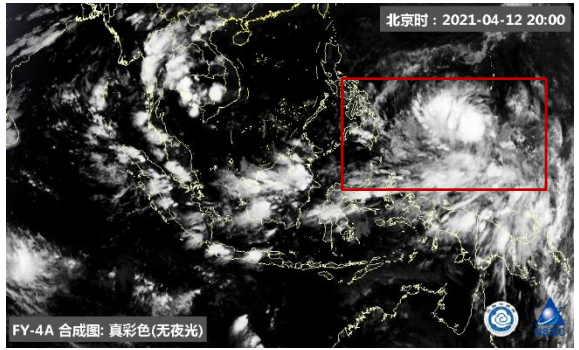
2-Day TC Formation Chance

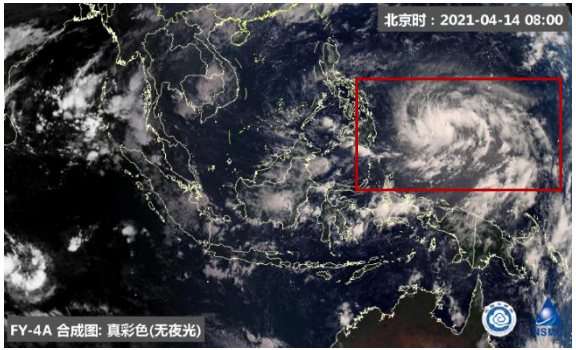


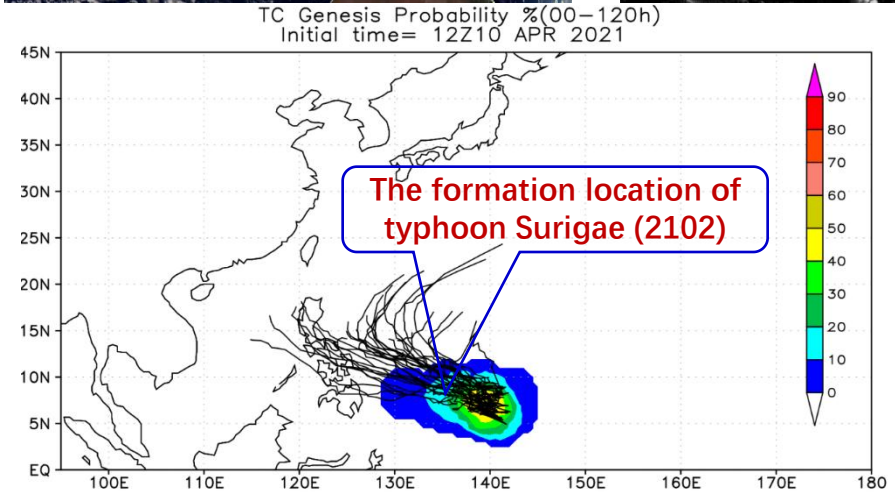
Typhoon Forecasting : TC Genesis Probability

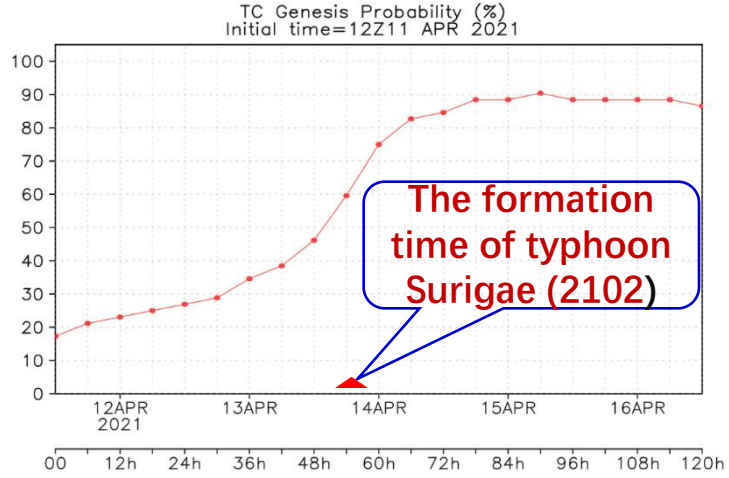
5-Day TC Genesis Probability









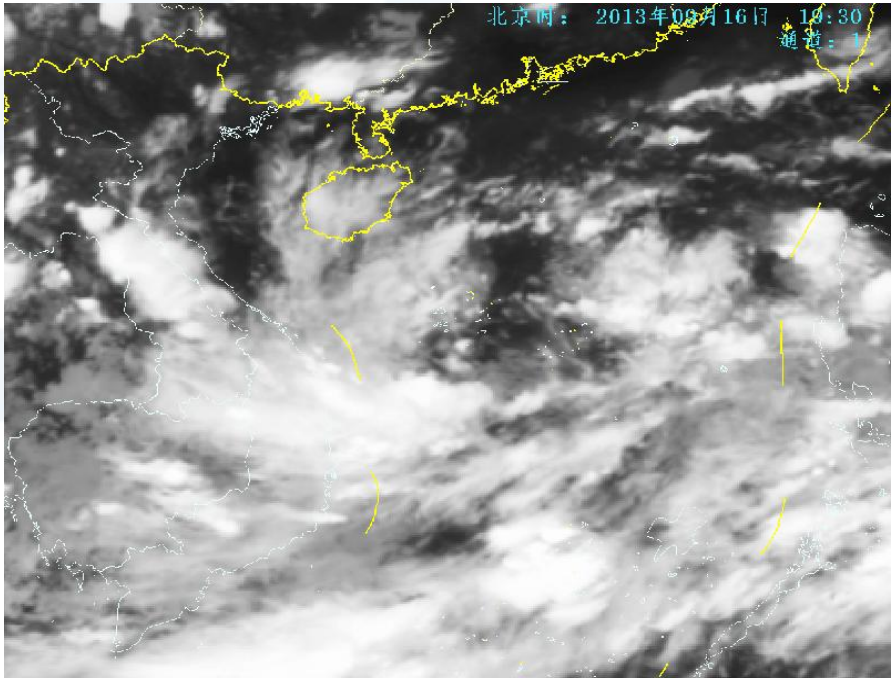


The products can show formation potential during the next 5 days, and also can increase forecaster confidence.

Conclusions

- The large-scale circulation is very important for TC genesis. About 70% TCs form in Mason trough. Monsoon trough can provide the most favorable conditions for TC genesis . The probability of DB in monsoon trough that can develop tropical depression is much higher than that in non monsoon trough. And The cluster of TCs usually occur in monsoon trough.
- During the process of MTC formation, there are usually more than two MCSs near the MTC formation position during 48 hours prior to MTC formation. MCSs are quite critical in determining the timing and whether the system is formation or non-formation.
- TC genesis probability technique basing on the ensemble forecast system can provide is useful guidance for TC genesis forecasting, especially multi-model probabilities can give most reliable forecasts guidance.

Conclusions



However, accurately forecasting TC genesis is still a big Challenge.

~Thanks~

Email： lvxy@cma.gov.cn

POP2 Collaborative Discussion (CoDi)

Forum on TC Analysis and Forecast

Motivation and progress

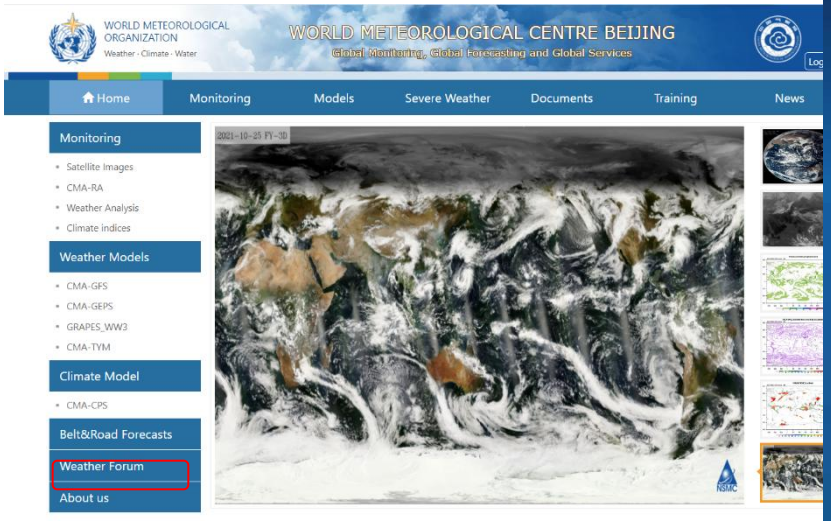
Collaborative Discussion (CoDi)

forum on Tropical Cyclone (TC) Analysis and Forecast

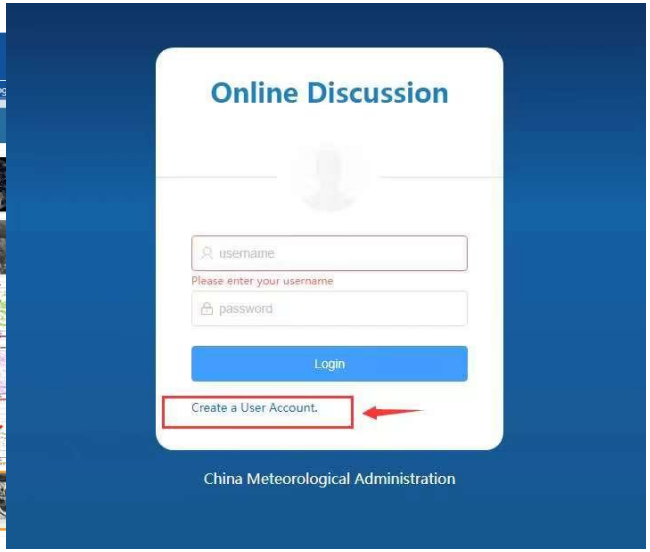
- ✓ **To set up a mailing list and web-based discussion platform to facilitate real-time exchange of information**
- ✓ **To encourage Members' typhoon forecasters to use this platform for instant or real time online discussions or information exchange**
- ✓ **To run routinely.**

Motivation and progress

For special TC cases we can share analysis and forecast products information that facilitate assessment of tropical cyclone situations. Users can join or create , make discussion groups, and communicate through audio/video online conference.



http://www.wmc-bj.net/



http://webchat.nmc.cn

New developments

- The new training materials will be divided into six categories based on purpose of usage,
- Q& A will be recommended by providing the mailing list of all presenters.

TC location analysis technique

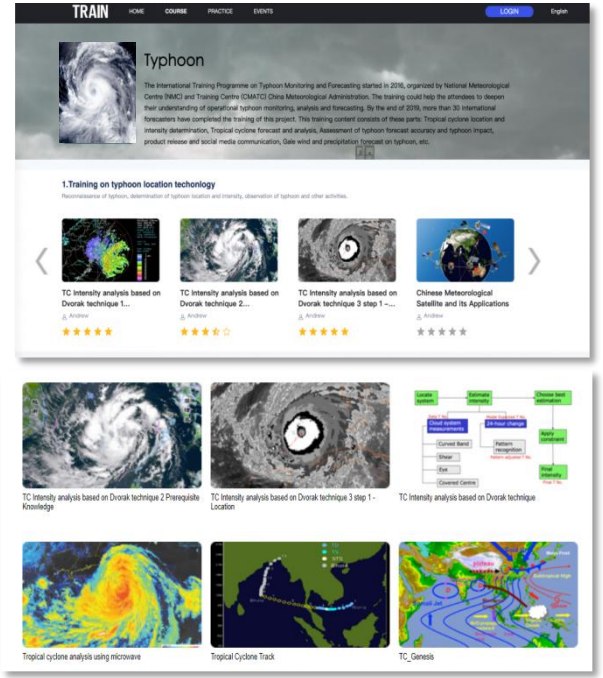
Satellite data introduction
Radar data introduction
Observation data introduction

TC intensity analysis technique

Dvorak technique 1-6
TC analysis using microwave
TC structure using radar data
Best track database and application

TC forecast technique

Synoptic analysis based on weather map
NWP and EPS introduction
TC track forecast
TC genesis forecast
Gales winds and precipitation
Storm surge and wave forecast



TC warning system

Social media cooperation and feedback
Public reaction and interaction

Operation platform

MICAPS_V4.0 introduction
SWAP introduction
TYMIS introduction

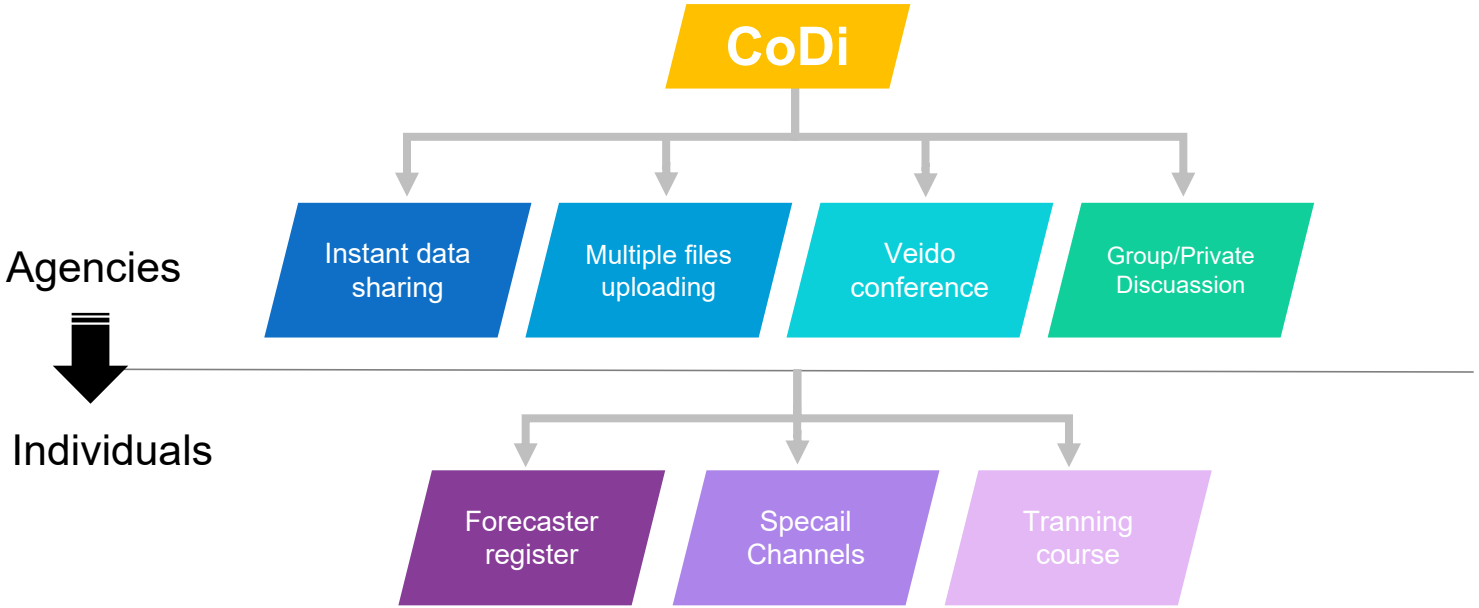
TC reanalysis

High impact TC cases reanalysis
TC forecast verification
TC impact evaluation

Function expansion

CoDi has already developed fundamental features to meet routine operational needs.

It should be expanded to address more complex application scenarios.



New developments

Arrange special Q&A time for trainees On CoDi

The 7th training course had 172 international trainees from 48 countries in 2022.

The 6th training course had 133 international trainees from 30 countries in 2021.