A modeling study of the influence of multi-scale waves on tropical cyclone formation in June 2004

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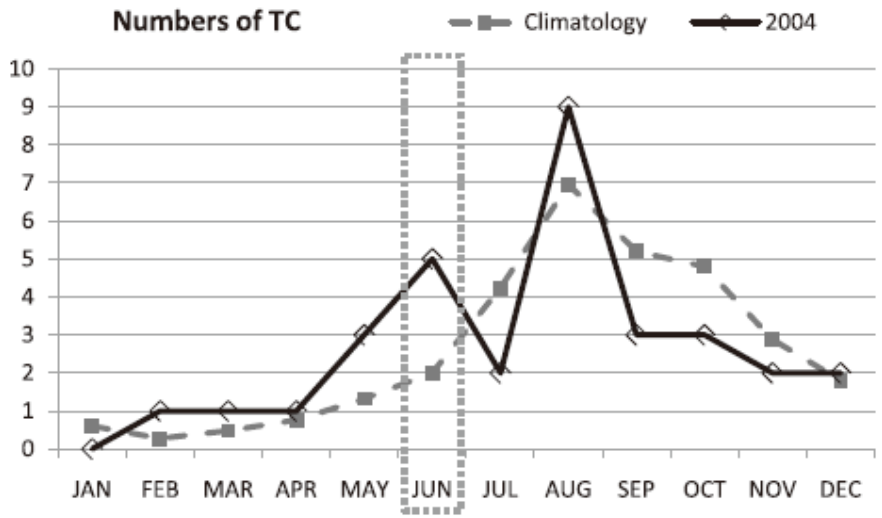
TY season: Jul. to Oct.

June : transition month

Large-scale conditions are not favorable!



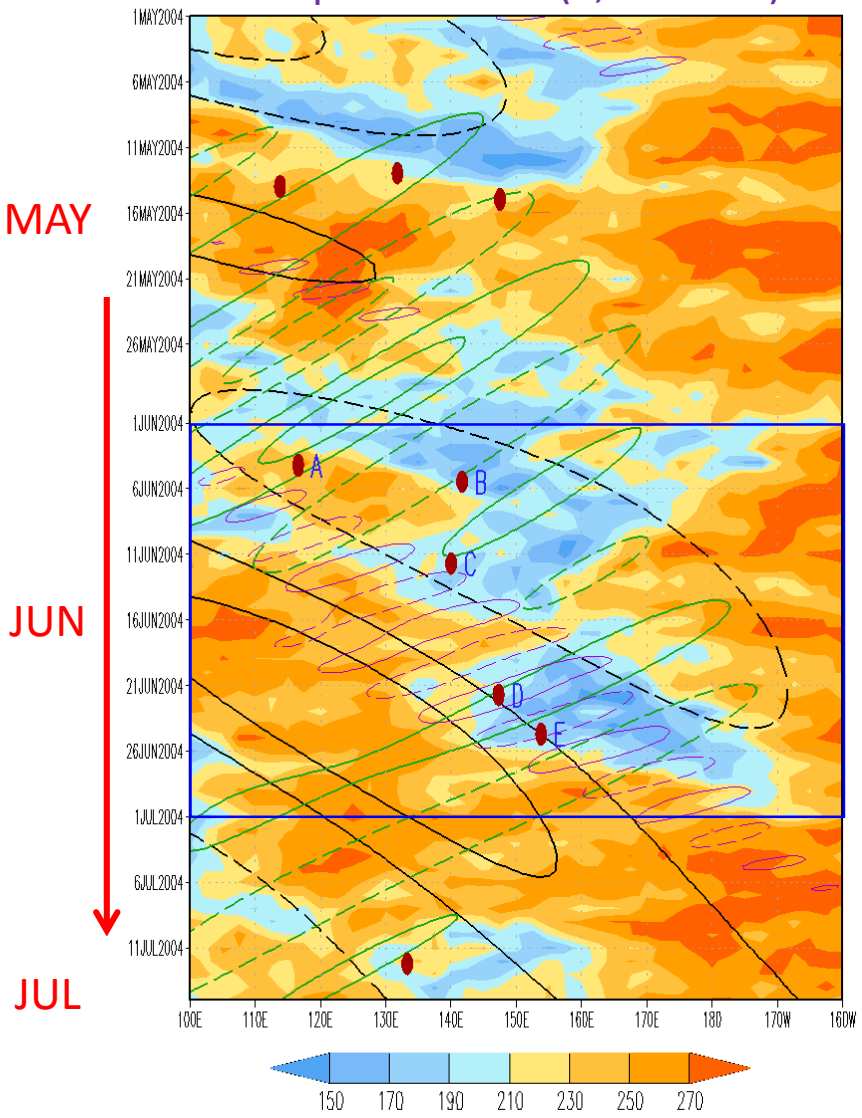
But the record breaking five TCs formed in June 2004

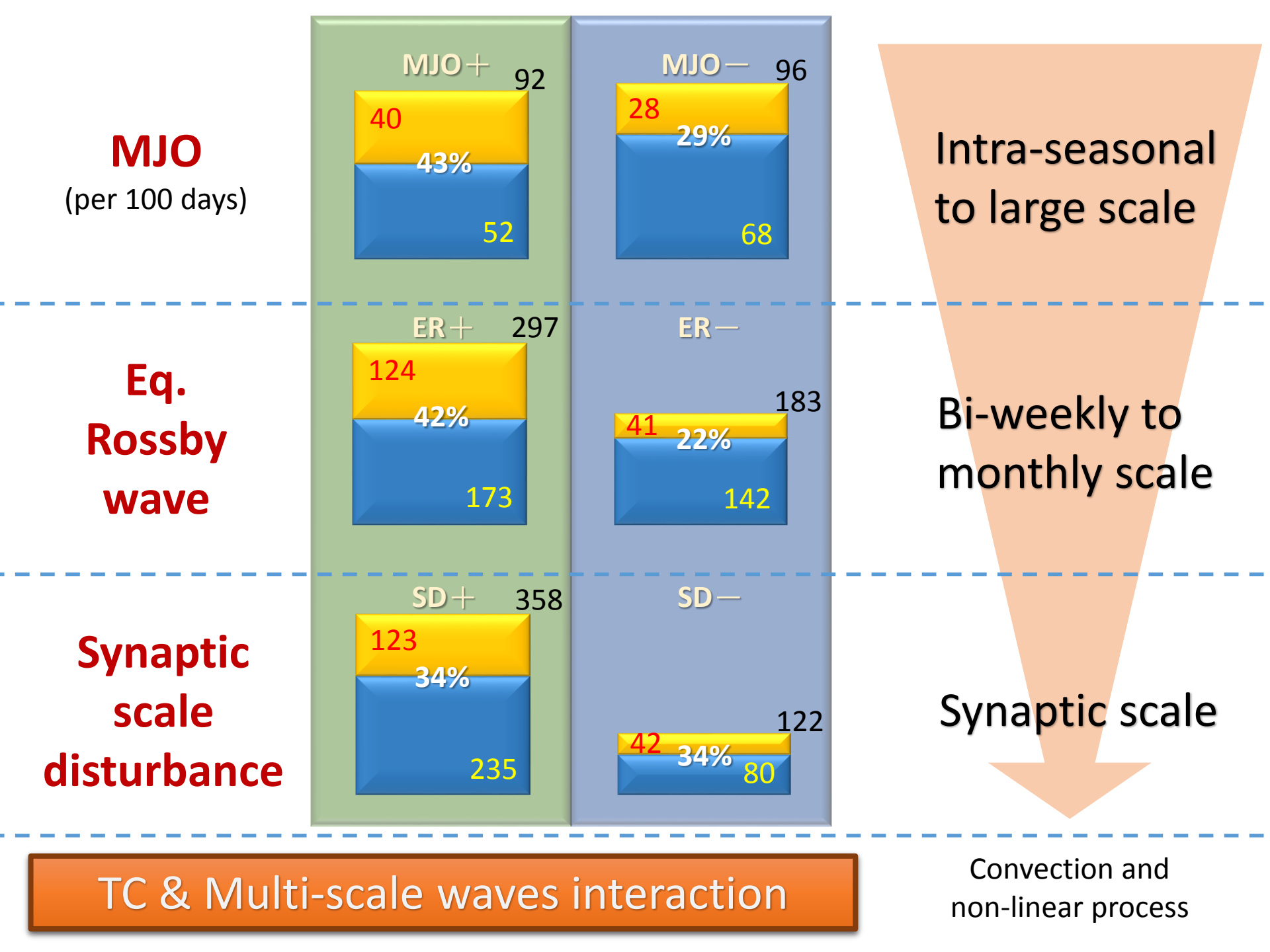
Color: Total OLR (5S-5N)

Black: MJO (OLR, 5S-5N)

Green: ER (VOR, 5N-15N)

Purple: MRGTD (V, 5N-15N)




MJO
(per 100 days)
MJO＋
92
40
43%
52
MJO－
96
28
29%
68
Intra-seasonal
to large scale
Eq.
Rossby
wave
ER＋
297
124
42%
173
ER－
183
41
22%
142
Bi-weekly to
monthly scale
Synaptic
scale
disturbance
SD＋
358
123
34%
235
SD－
122
42
34%
80
Synaptic scale
TC & Multi-scale waves interaction
Convection and
non-linear process

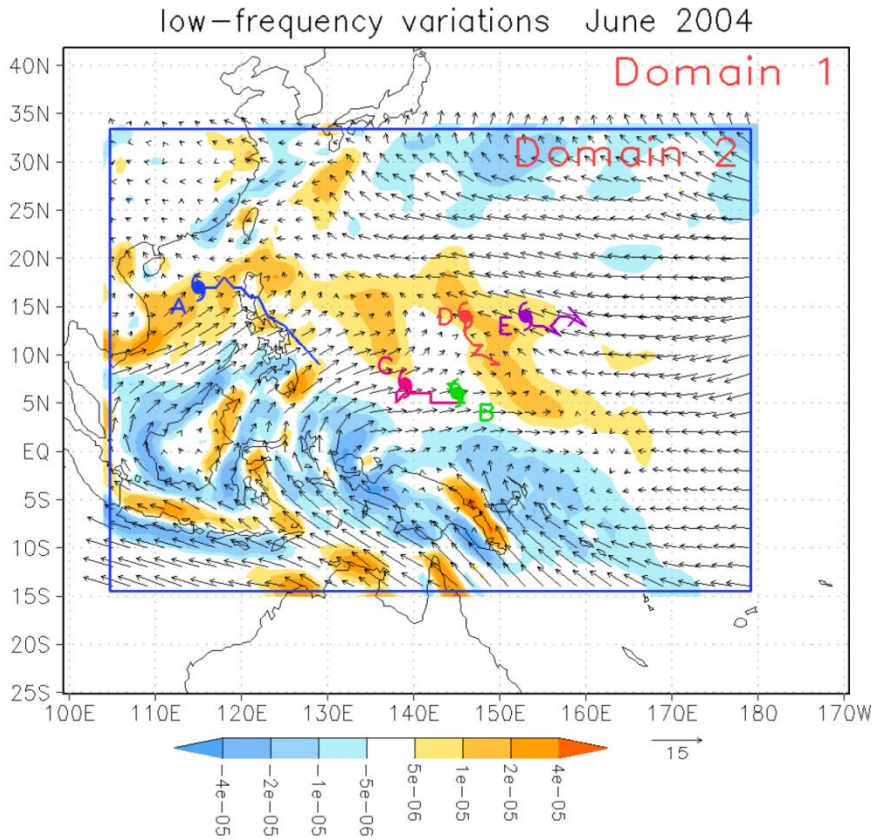
WRF experiments design:

Model Setting

Two domain: 36, 12 km
35 vertical layers
Buffer zone: 10 points
Cumulus scheme: Grell 3D ensemble scheme
Microphysics scheme: WSM 6-class scheme
PBL scheme: MYJ PBL scheme
IC & BC: NCEP Global Final analysis data (FNL)
No TC initialization scheme

Space-time filter (*Wheeler and Kiladis,* 1999)

Wave	wave number	period	propagation
MJO	0 – 5	30 – 90 days	eastward
ER	1 – 10	10 – 40 days	westward



Experiment	IC & BC data
CTL	unfiltered NCEP FNL analysis data
noMJO	analysis data excluding MJO signal
noER	analysis data excluding Rossby wave signal
noMJOER	analysis data excluding both MJO and Rossby wave signal

Same setting for all experiments, except the IC &BC data

sensitivity of removed fields

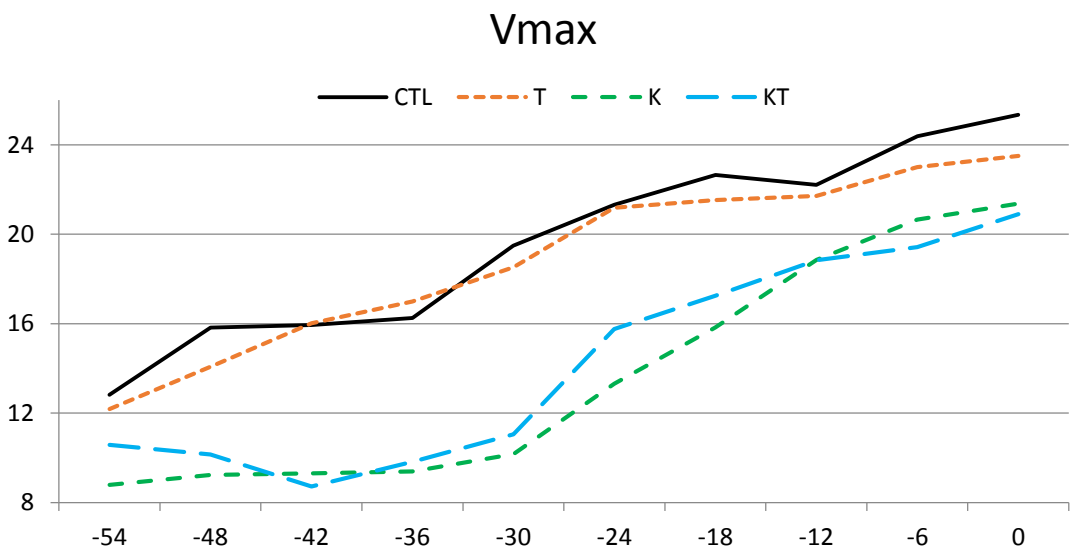
Experiments without wave signal in

T: Thermodynamics fields (H, T, Q)

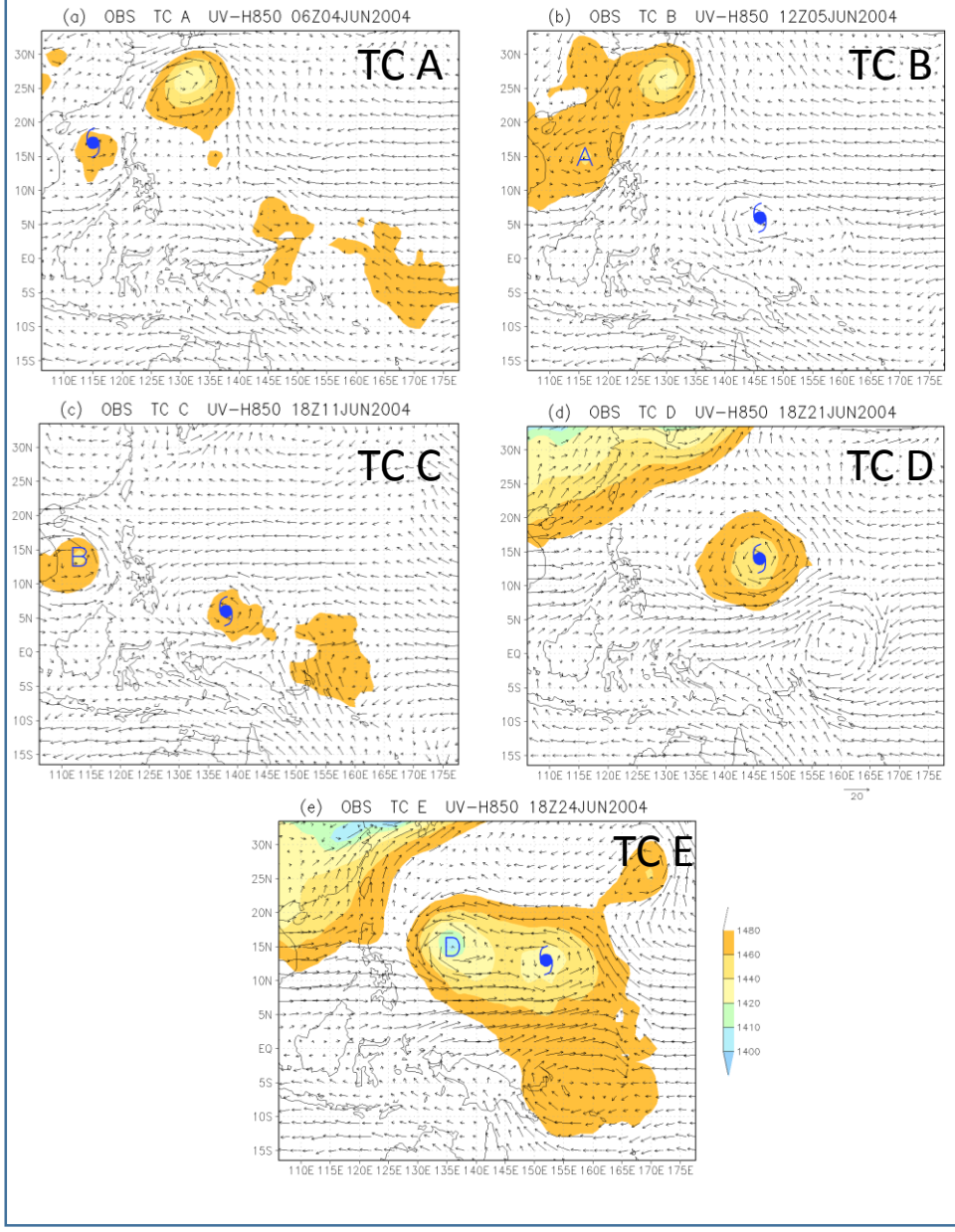
K: Kinetic fields (U, V)

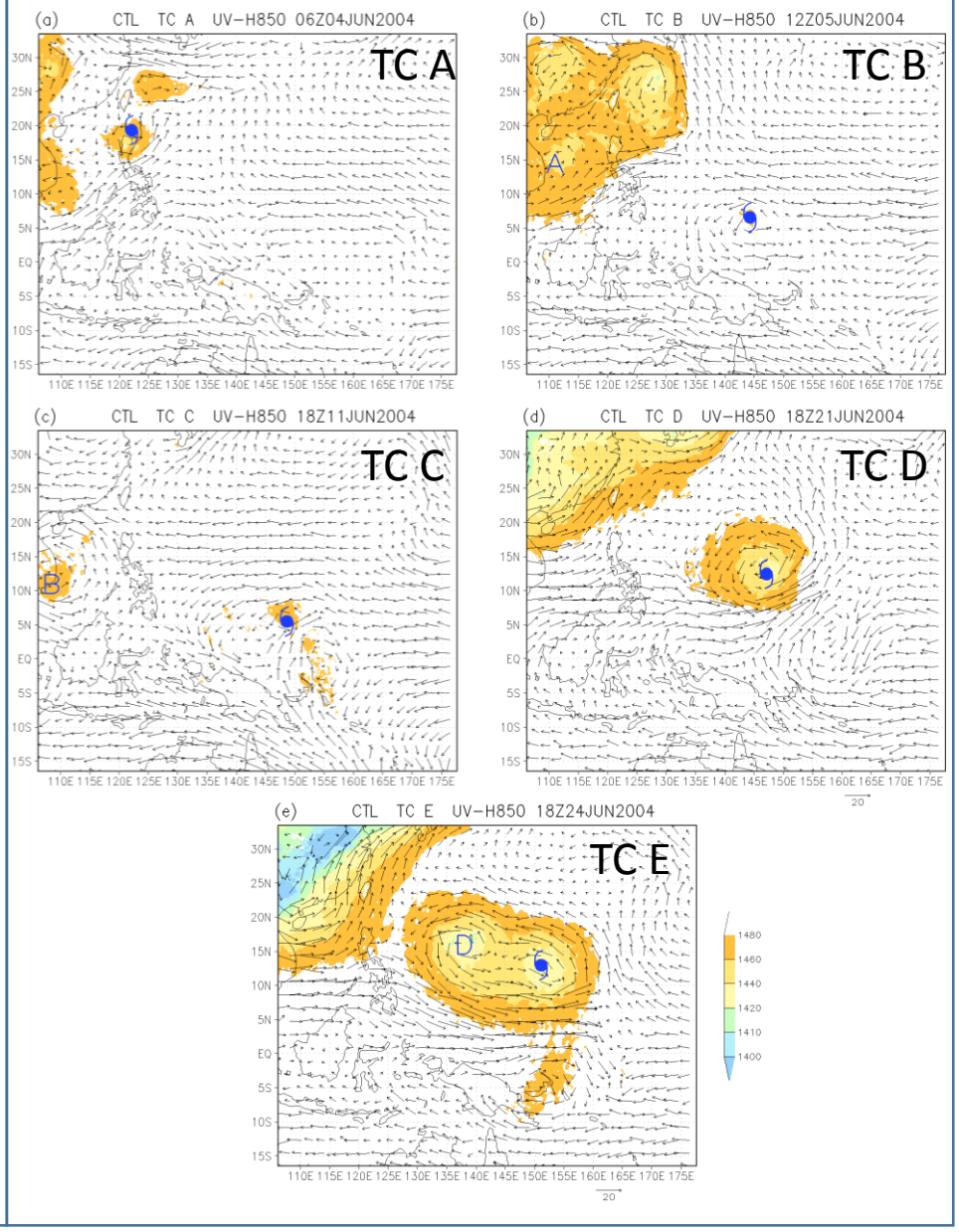
KT: Kinetic and Thermodynamics fields (U, V, H, T, Q)

CTL: unfiltered IC & BC



Analysis HUV850 Simulation





Tropical Depression (TD):

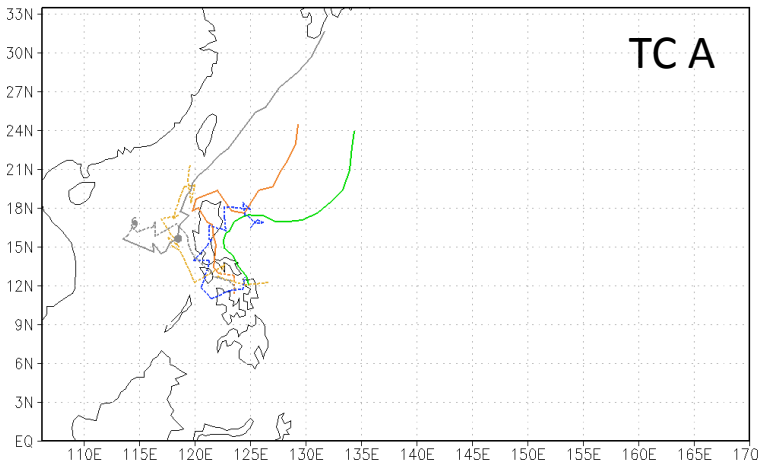
A tropical cyclone in which the maximum sustained wind speed is constantly between 20 and 34 knots. Depressions have a closed circulation.

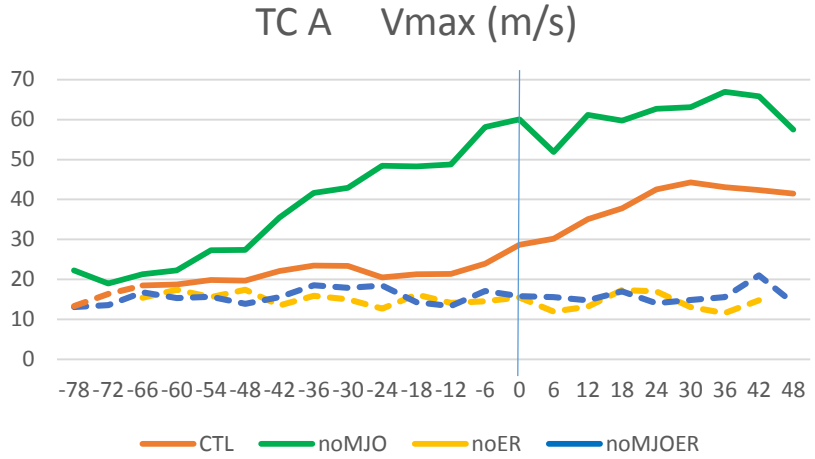
1. closed circulation
2. Vmax > 25 knots (12.5 m s^{-1})
3. 14400 km^2 area-mean vorticity > $5x10^{-5}$ s^{-1}, and sustain more than 12 hours.

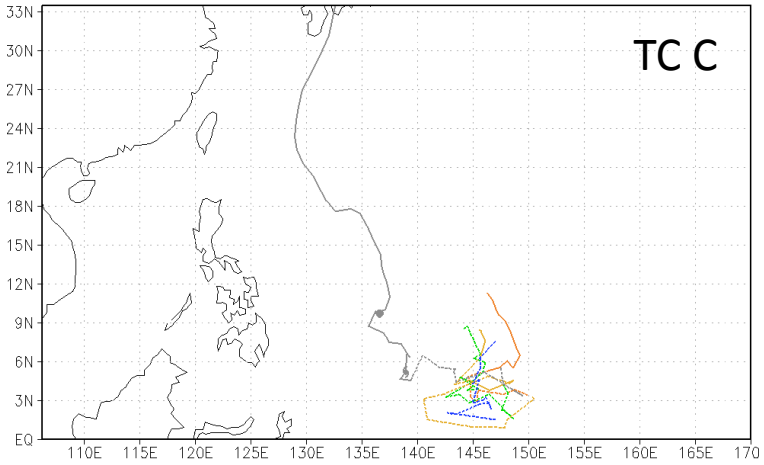
Tropical Storm (TS)

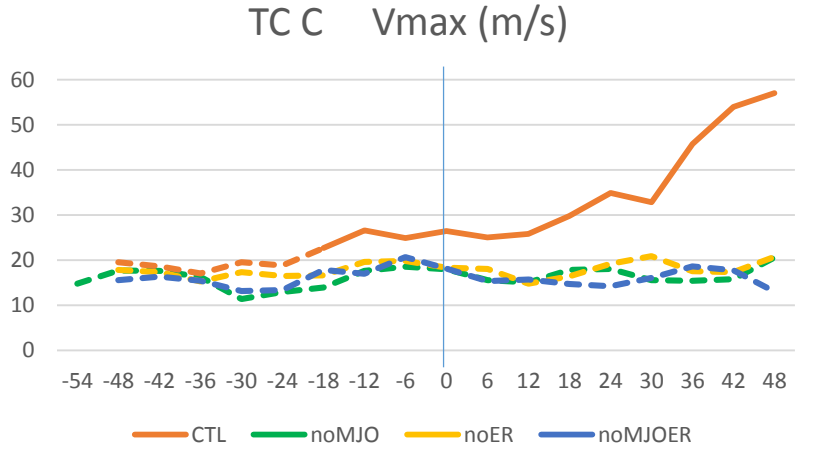
A tropical cyclone in which the maximum sustained wind speed equal or exceed 34 knots.

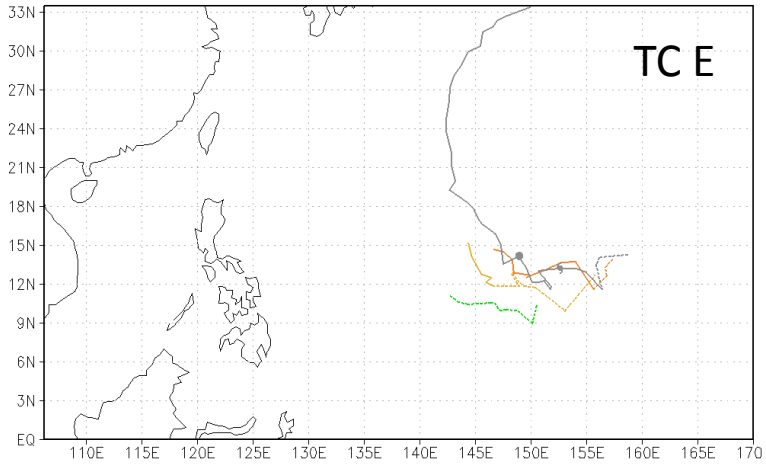
1. closed circulation
2. Vmax > 34 knots (17.5 m s^{-1})
3. 14400 km^2 area-mean vorticity > 10^{-4} s^{-1}, and sustain more than 12 hours.

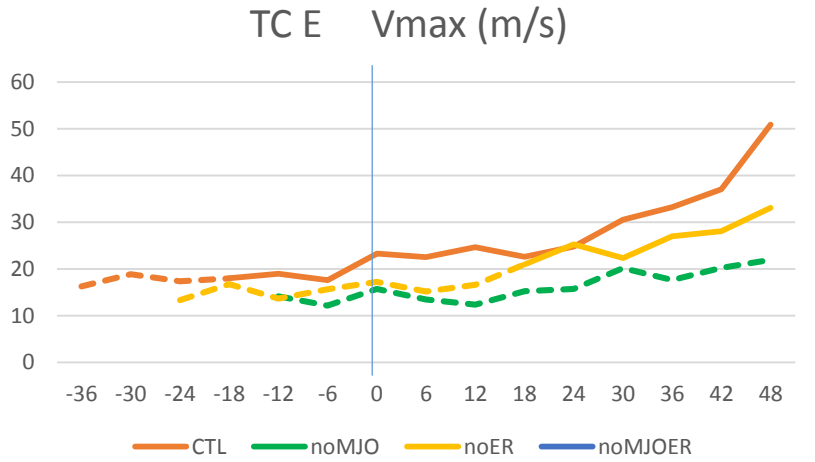

TC A
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
110E 115E 120E 125E 130E 135E 140E 145E 150E 155E 160E 165E 170

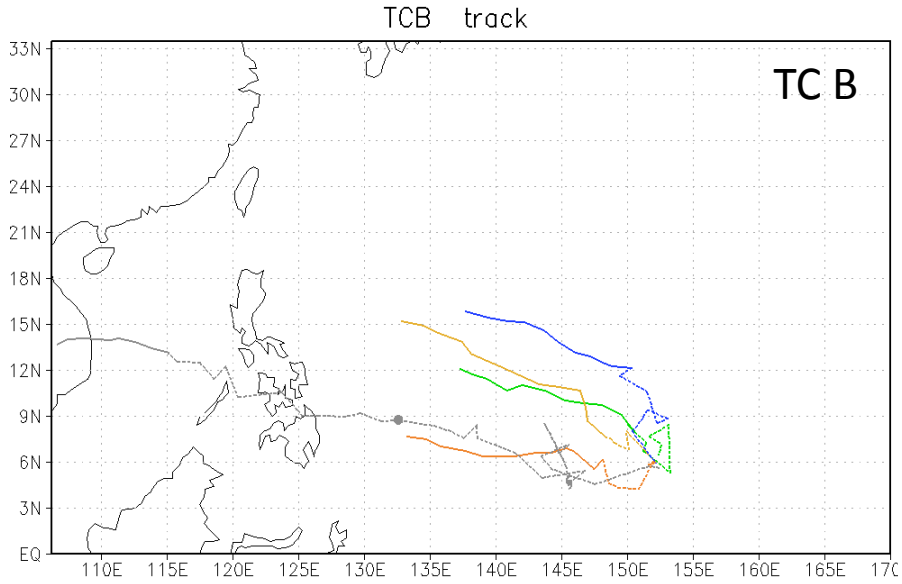

TC A Vmax (m/s)
70
60
50
40
30
20
10
0
-78 -72 -66 -60 -54 -48 -42 -36 -30 -24 -18 -12 -6 0 6 12 18 24 30 36 42 48
CTL
noMJO
noER
noMJOER

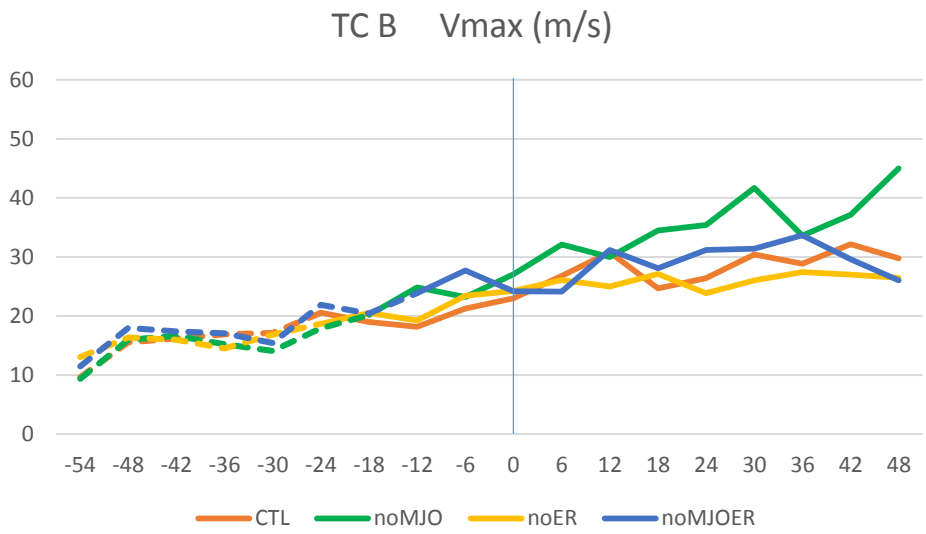

TC C
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
110E 115E 120E 125E 130E 135E 140E 145E 150E 155E 160E 165E 170

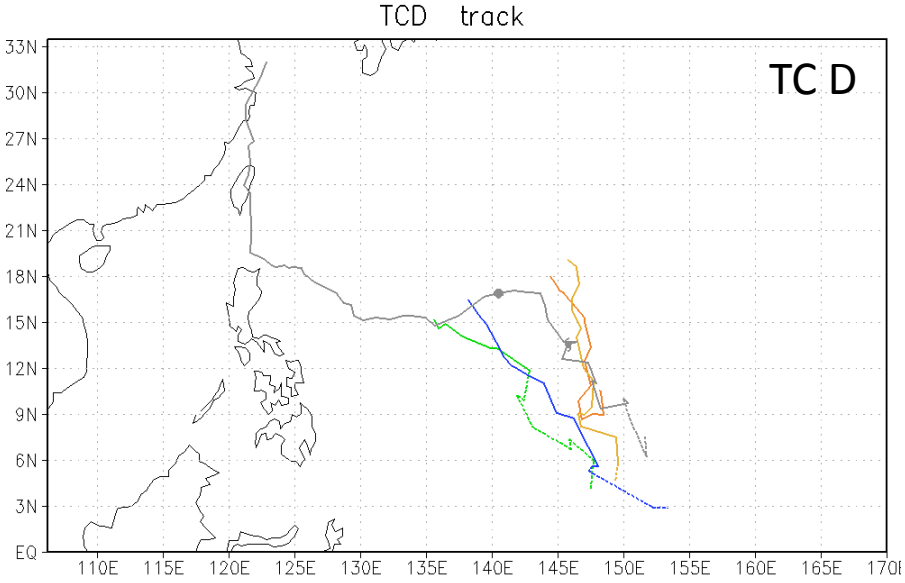

TC C Vmax (m/s)
60
50
40
30
20
10
0
-54 -48 -42 -36 -30 -24 -18 -12 -6 0 6 12 18 24 30 36 42 48
CTL
noMJO
noER
noMJOER

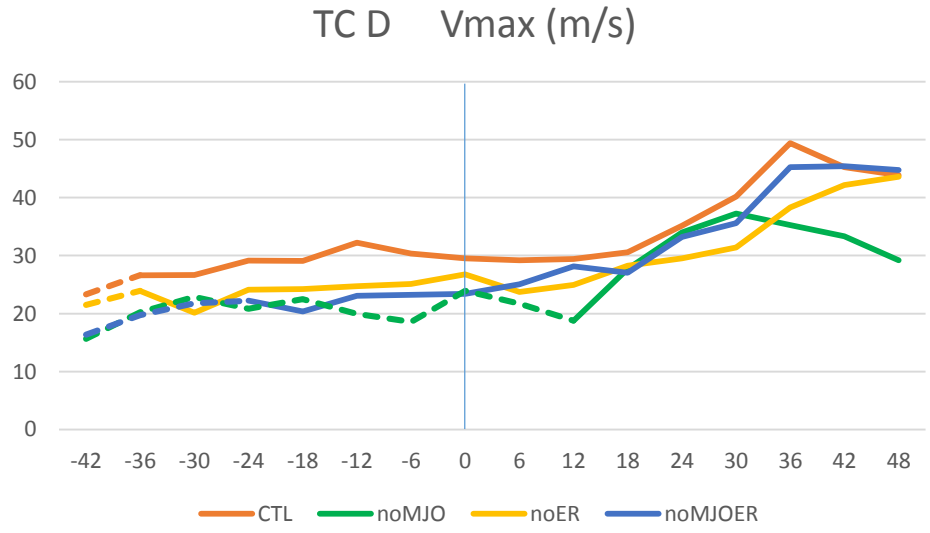

TC E
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
110E 115E 120E 125E 130E 135E 140E 145E 150E 155E 160E 165E 170


TC E Vmax (m/s)
60
50
40
30
20
10
0
-36 -30 -24 -18 -12 -6 0 6 12 18 24 30 36 42 48
CTL
noMJO
noER
noMJOER


TCB track
TC B
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
110E
115E
120E
125E
130E
135E
140E
145E
150E
155E
160E
165E


TC B Vmax (m/s)
60
50
40
30
20
10
0
-54 -48 -42 -36 -30 -24 -18 -12 -6 0 6 12 18 24 30 36 42 48
CTL
noMJO
noER
noMJOER


TCD track
TC D
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
110E
115E
120E
125E
130E
135E
140E
145E
150E
155E
160E
165E

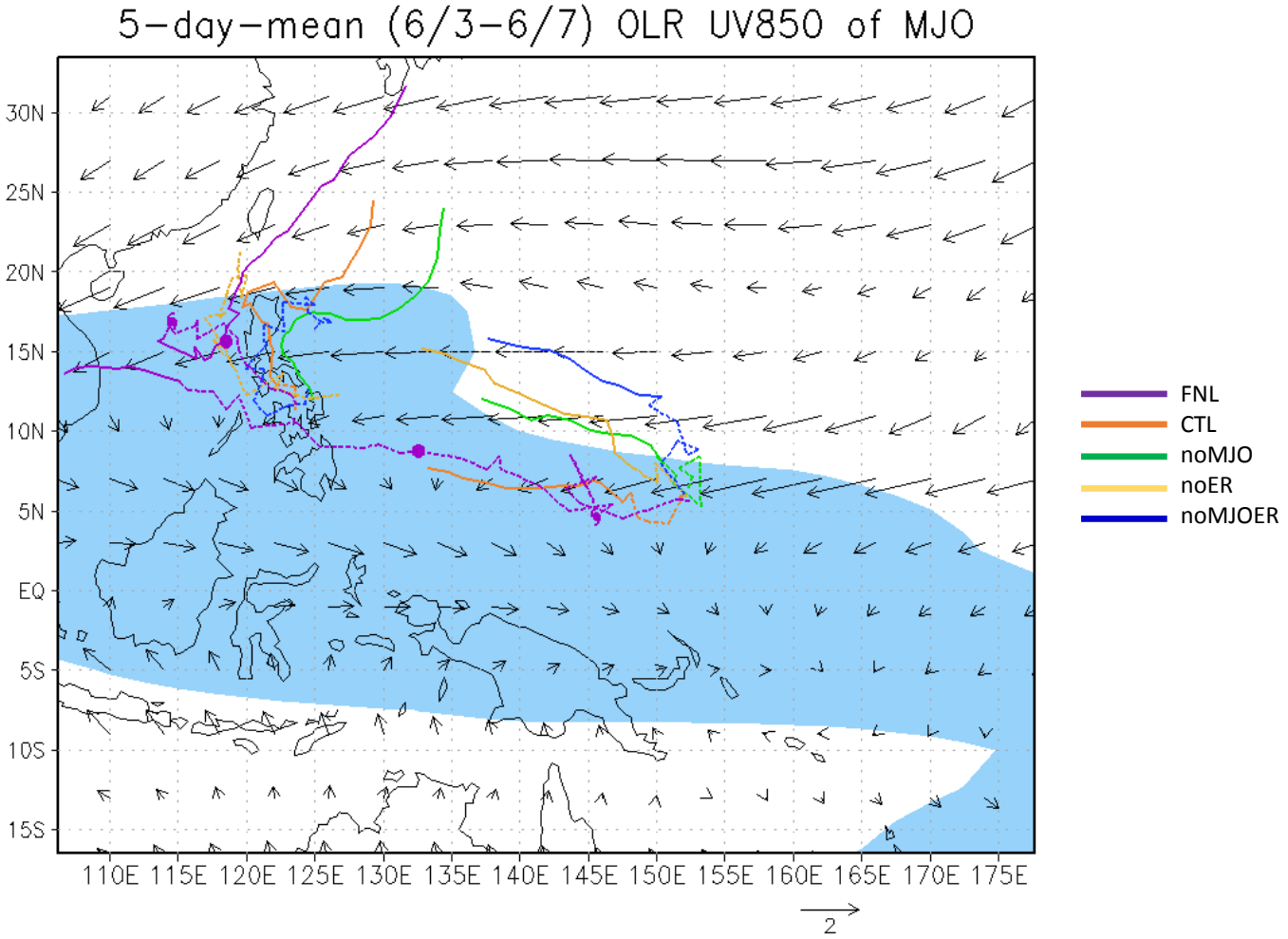

TC D Vmax (m/s)
60
50
40
30
20
10
0
-42 -36 -30 -24 -18 -12 -6 0 6 12 18 24 30 36 42 48
CTL
noMJO
noER
noMJOER

	OBS	CTL	noMJO	noER	noMJO-ER
TC A	TS	TS	TS↑	TCn	TCn
TC B	TS	TS	TS↑	TS	TS
TC C	TS	TS	TCn	TCn	TCn
TC D	TS	TS	TS↓	TS	TS
TC E	TS	TS	TCn	TS↓	disappear

Overall speaking

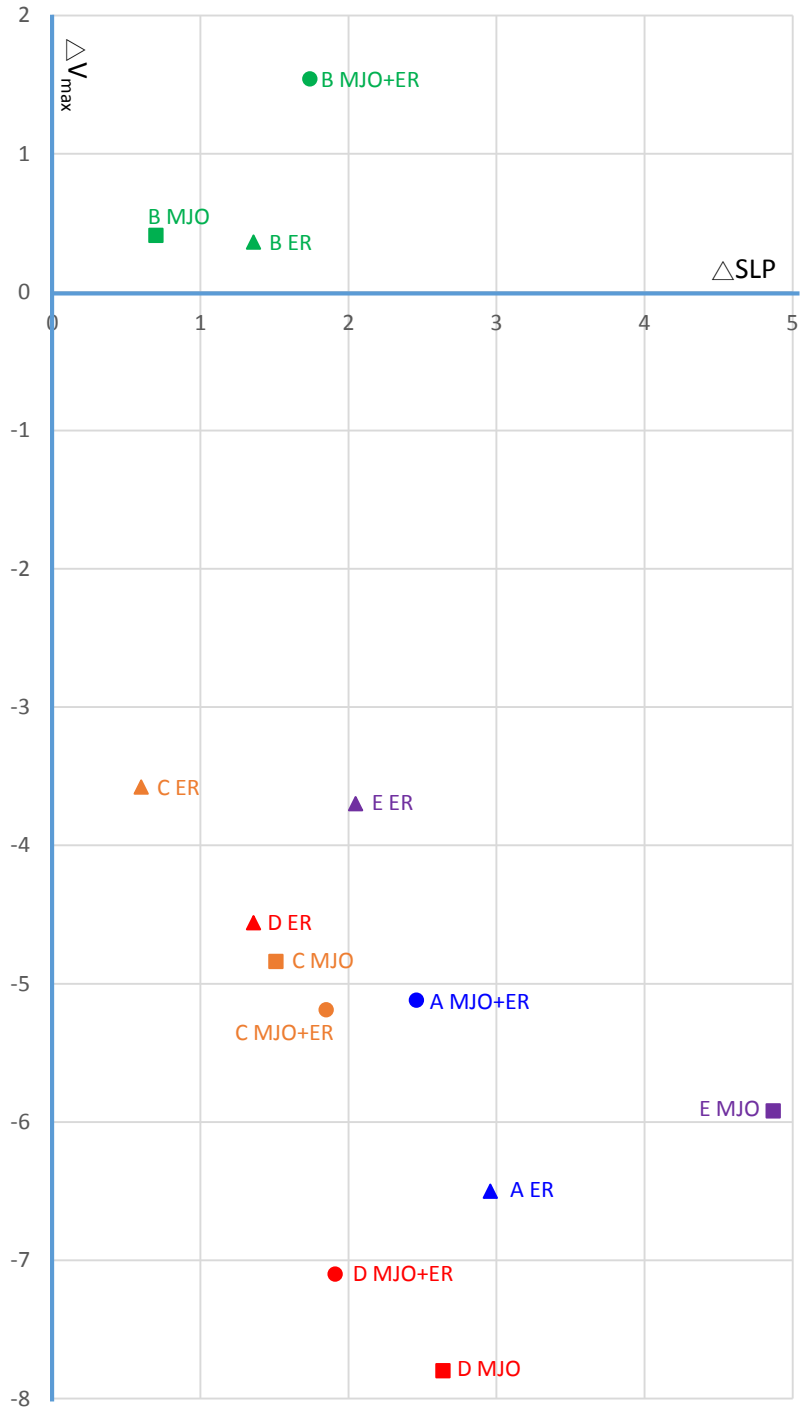
- Removing LF forcing, TC tracks change
  TC intensity weaken
  TS → TD, even disappear

Five days mean MJO signal



Heat flux during developing period (W m^{-2})

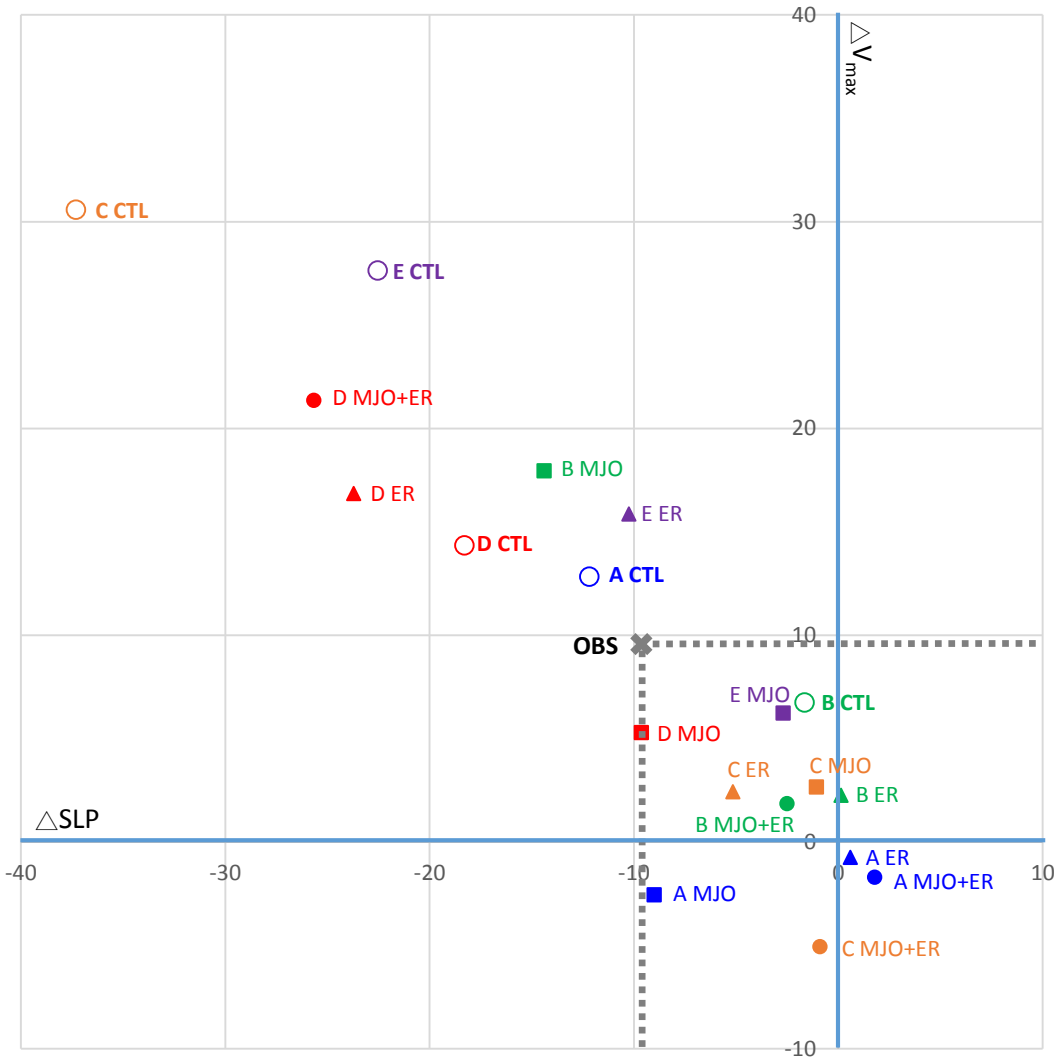
Heat flux	CTL	noMJO	noER	noMJOER
TC A	98.76	**159.12**	108.83	107.32
TC B	148.1	**162.0**	143.5	136.4



The differences of SLP (ΔSLP) and Vmax (ΔVmax) of initial disturbance between the CTL and each wave experiment at the warning time H(0) for the five TCs.

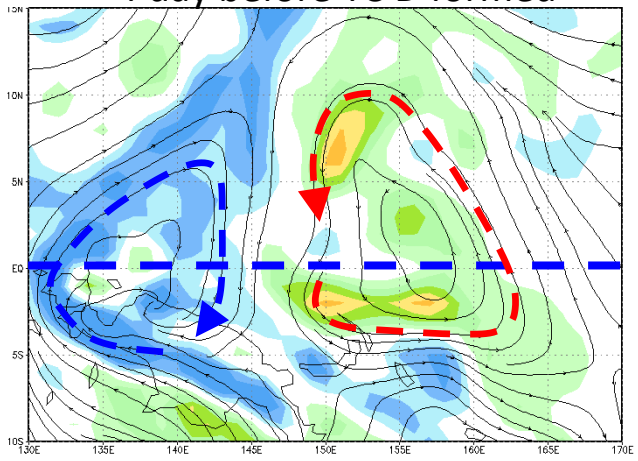
A positive (negative) ΔSLP (ΔVmax) denotes a weaker initial disturbance as a result of the missing wave.

An overall strengthening effect by large-scale waves on TC genesis, except TC B.

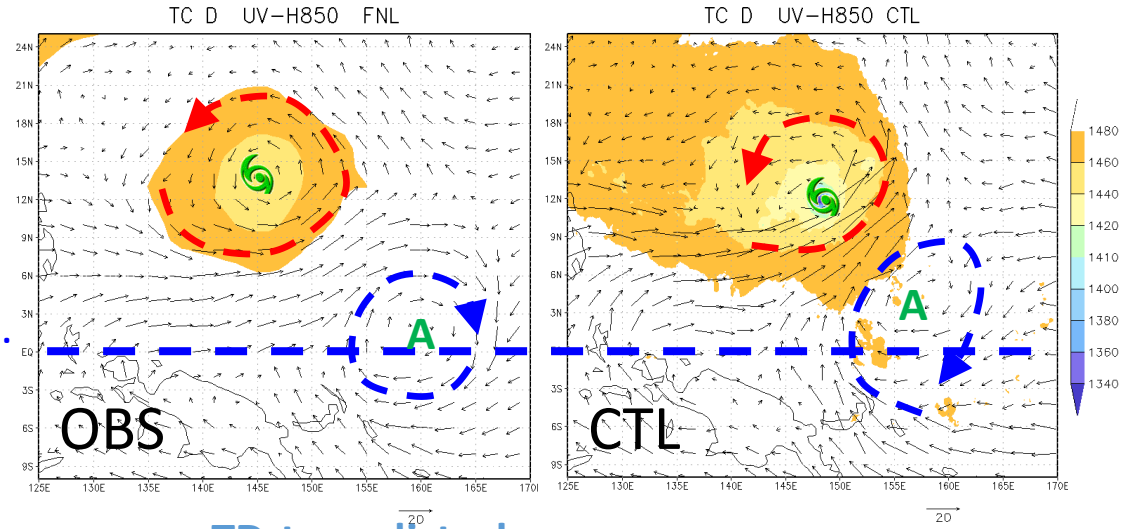


Intensification of observed and simulated TCs in all experiments in two days following the warning time in terms of ΔSLP and ΔVmax between the warning time H(0) and 48 hours after the warning time H(48) for the five TCs in June.

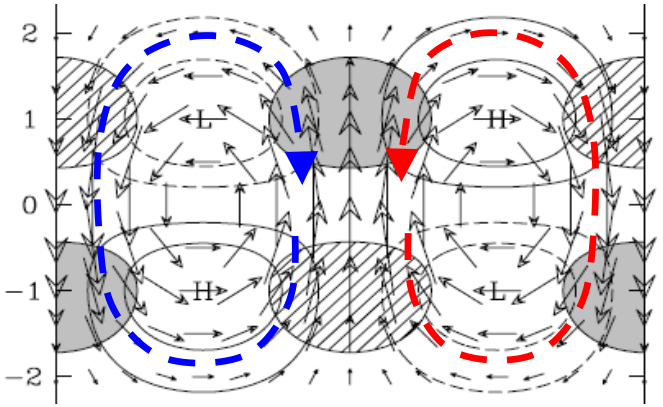
4 day before TC D formed



Eq.



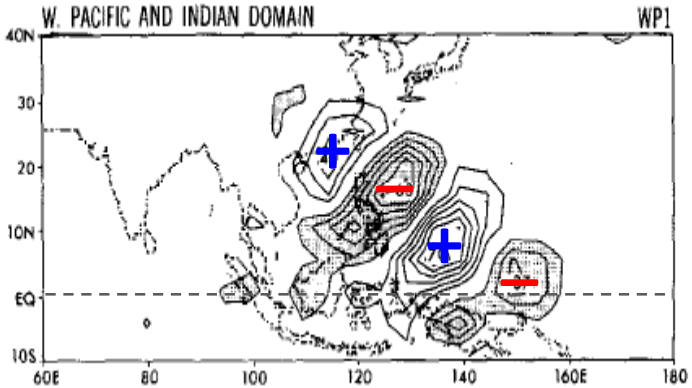
Theoretical MRG wave



Eq.

Kiladis et al., 2009

TD-type disturbance



Lau and Lau 1990

Moisture Flux Convergence (MFC)

($\times 10^{-6}$ g kg^{-1} s^{-1}) $MFC = -\nabla \cdot (q\overrightarrow{V_h})$

MFC	TC D
MJO	**0.56**
ER	-1.08
MRGTD	**12.85**

CTL

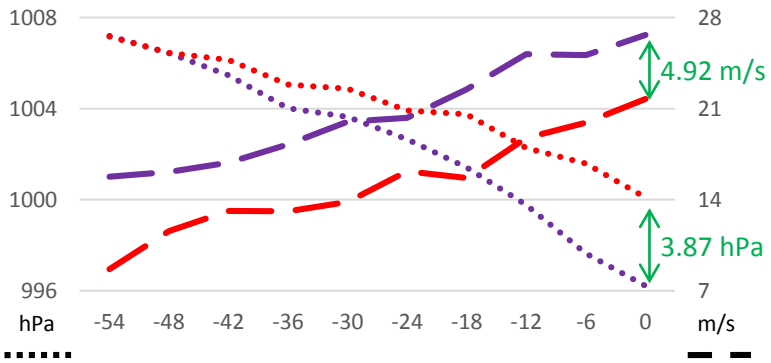
SLP

V_{max}

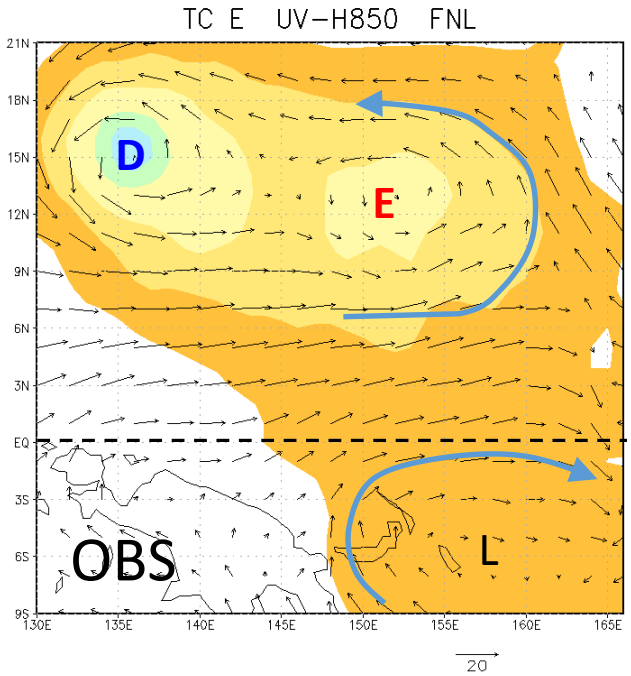
noMRGTD

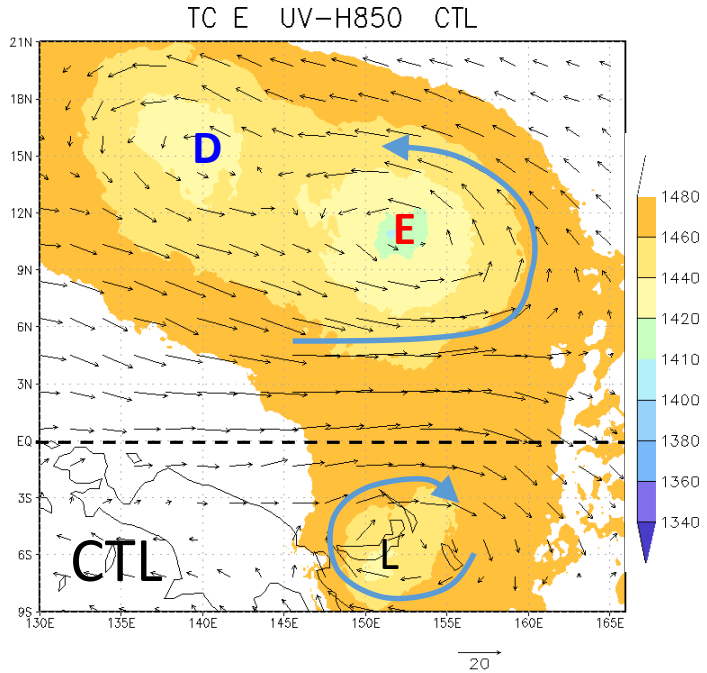
SLP

V_{max}

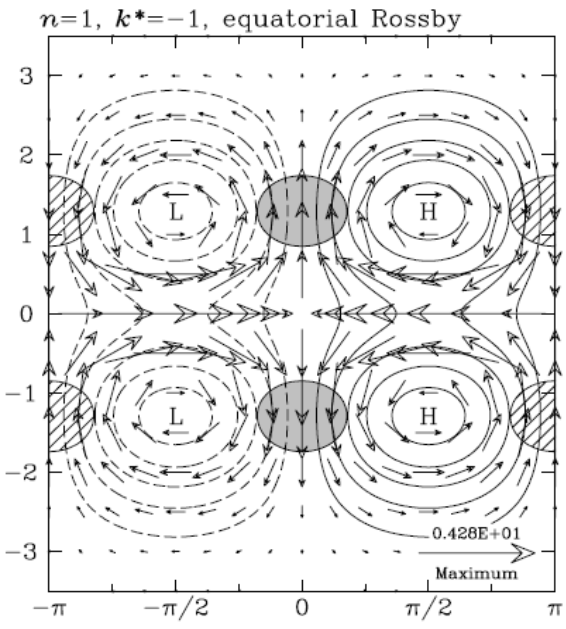


When TC E formed





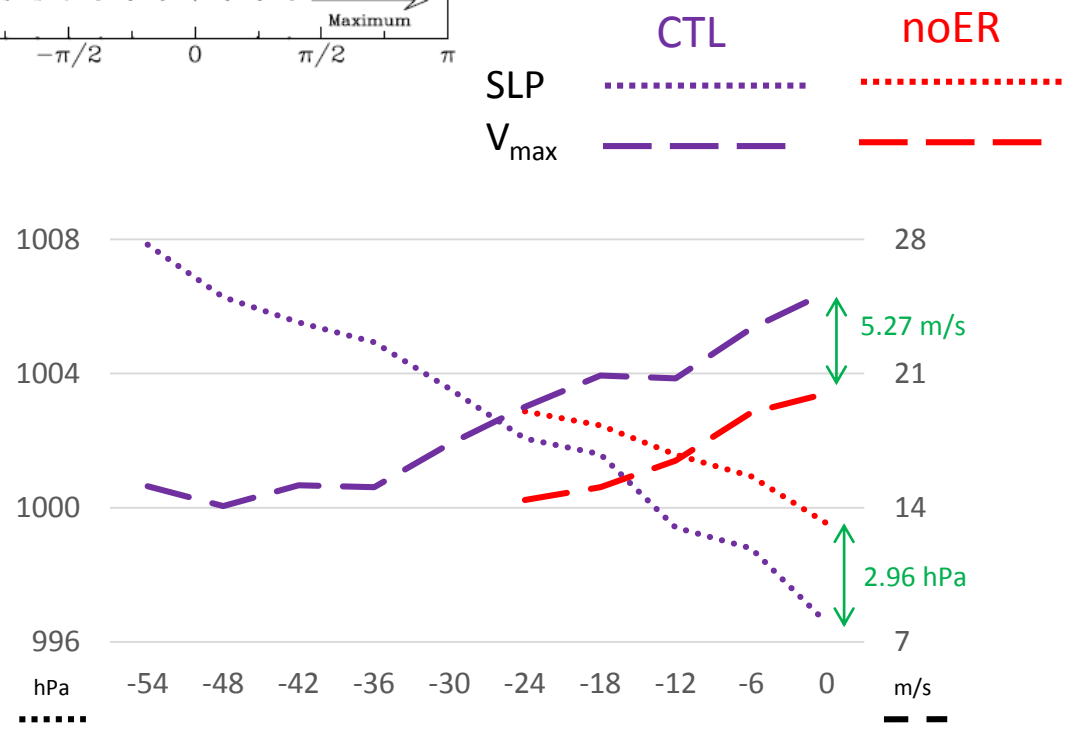
Theoretical n=1 Rossby wave



The formation of TC E is mainly contributed by ER wave

mean difference to CTL

TC E	SLP	V_{max}
no MJO	0.84	-2.56
no ER	**1.79**	**-4.92**
no MRGTD	-1.28	-0.39



Summary

- The numerical experiments by removing wave signal provide an overall supporting evidence to the observational analysis:
- By conducting a modeling study during this particular and complicated month with active multi-scale wave activities, the five TCs told us some stories:

  TC A → the influence of wave is not only on the intensity but also on the track,

  TC B → locally-developed system without any influence of wave,

  TC C → any wave can dominate the development,

  TC D → the contribution of synaptic wave is also important,

  TC E → the combined contribution of waves is more pronounced.

Thank you