Predicting the formation, development, and movement of tropical cyclones in the BIEN DONG sea.

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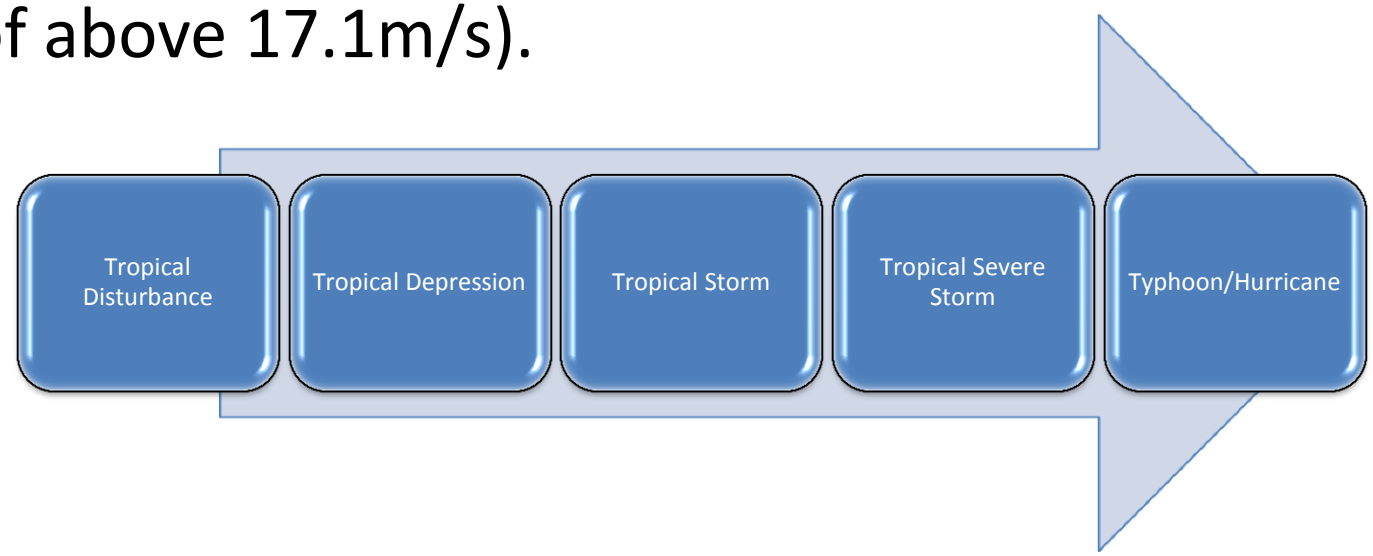
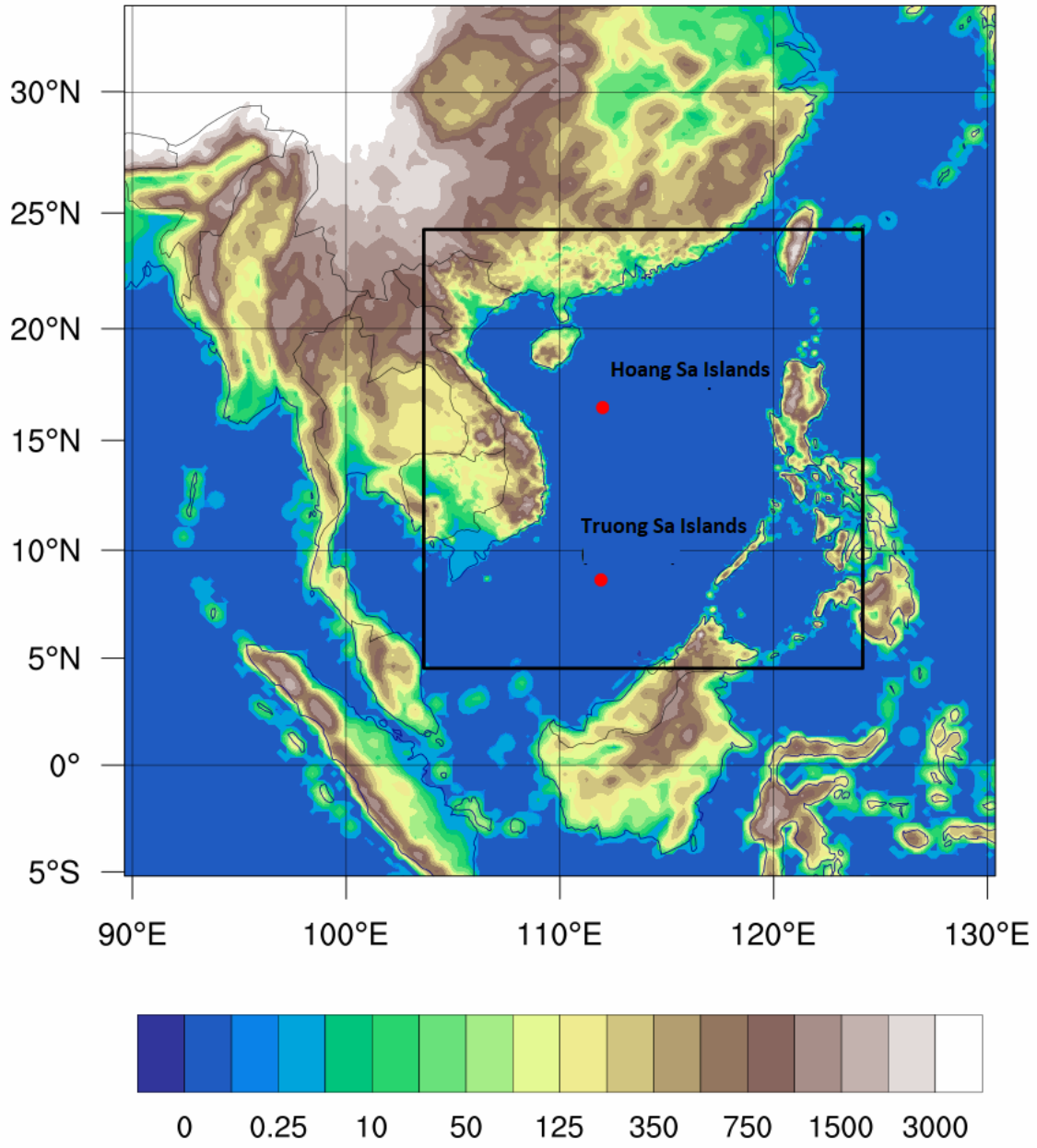
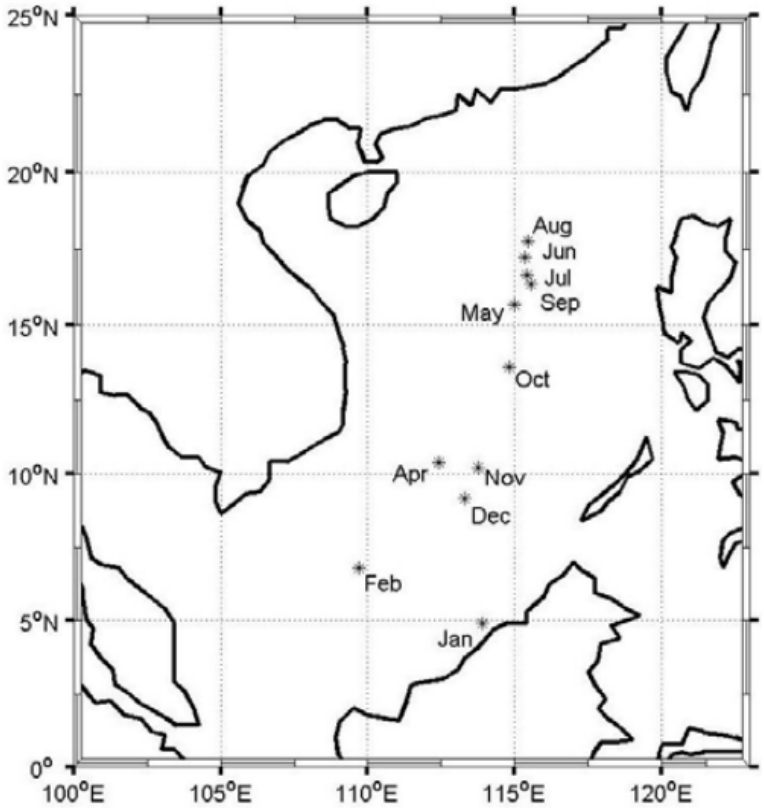
Introduction

- The “formation” is described as the process of a tropical disturbance to become a tropical depression with maximum sustained wind (MSW) reaching level 6 to 7 in Beaufort scale (10.8 – 17.1m/s).
- The “development” is known as the intensification of a tropical depression reaching the threshold of tropical storm or above (MSW in level 8, of above 17.1m/s).



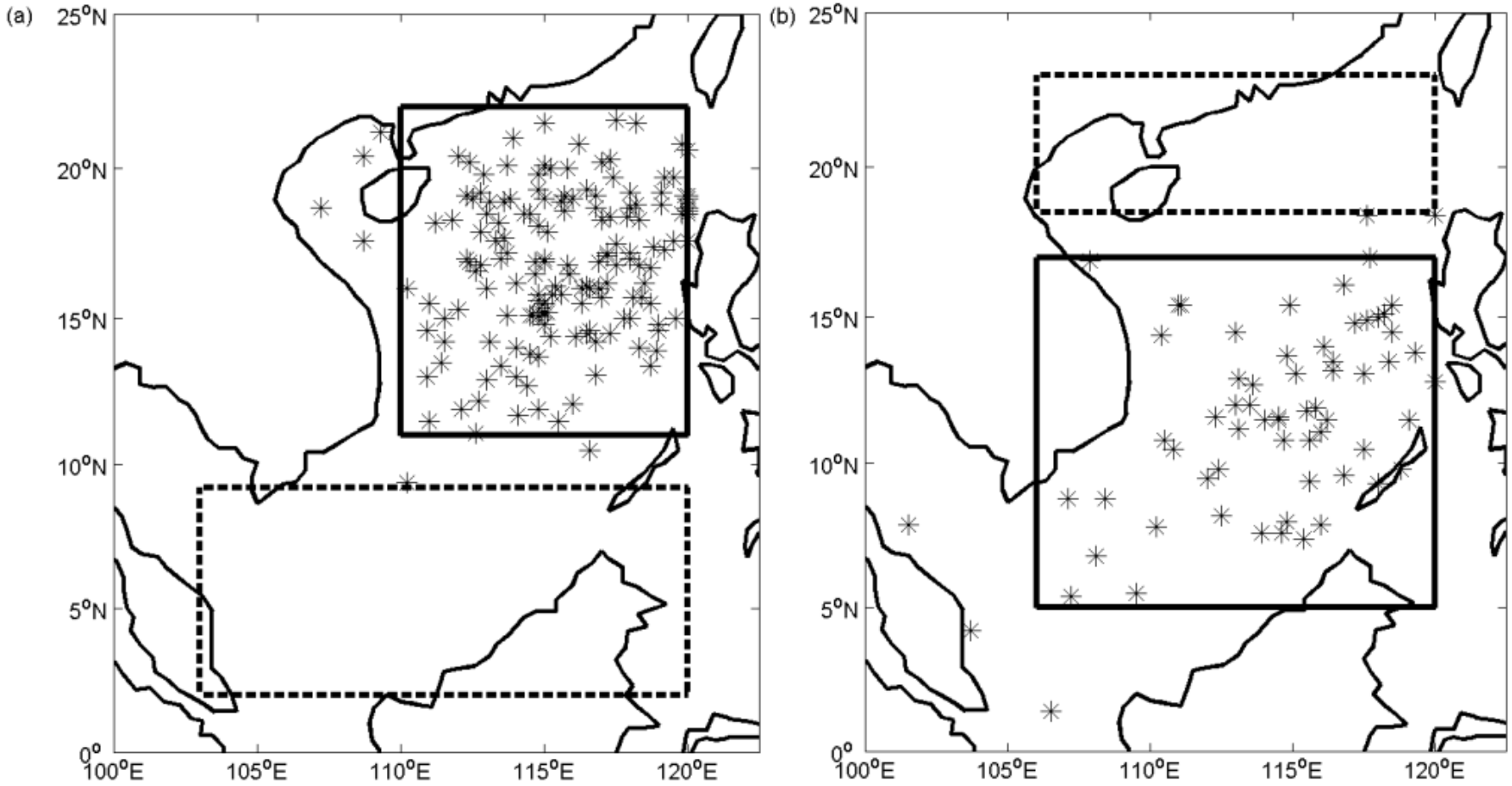
Bien Dong Sea – the region of interest.





Month	Latitude (°N)	Longitude (°E)	Standard deviation of latitude (°)	Standard deviation of longitude (°)
Jan	4.90	113.90	0.00	0.00
Feb	6.80	109.70	0.00	0.00
Apr	10.40	112.40	2.77	1.99
May	15.66	115.01	2.78	2.92
Jun	17.23	115.35	2.31	2.60
Jul	16.67	115.39	2.12	2.31
Aug	17.75	115.44	2.43	2.84
Sep	16.36	115.56	2.62	2.95
Oct	13.61	114.81	2.43	3.80
Nov	10.22	113.75	2.67	3.94
Dec	9.16	113.28	3.58	4.07

Lei Wang (2008)



Summer monsoon:

$$MFA: \begin{cases} 110°E - 120°E \\ 11°N - 22°N \end{cases}$$

$$NFA: \begin{cases} 103°E - 120°E \\ 2°N - 9.2°N \end{cases}$$

Winter monsoon:

$$MFA: \begin{cases} 106°E - 120°E \\ 5°N - 17°N \end{cases}$$

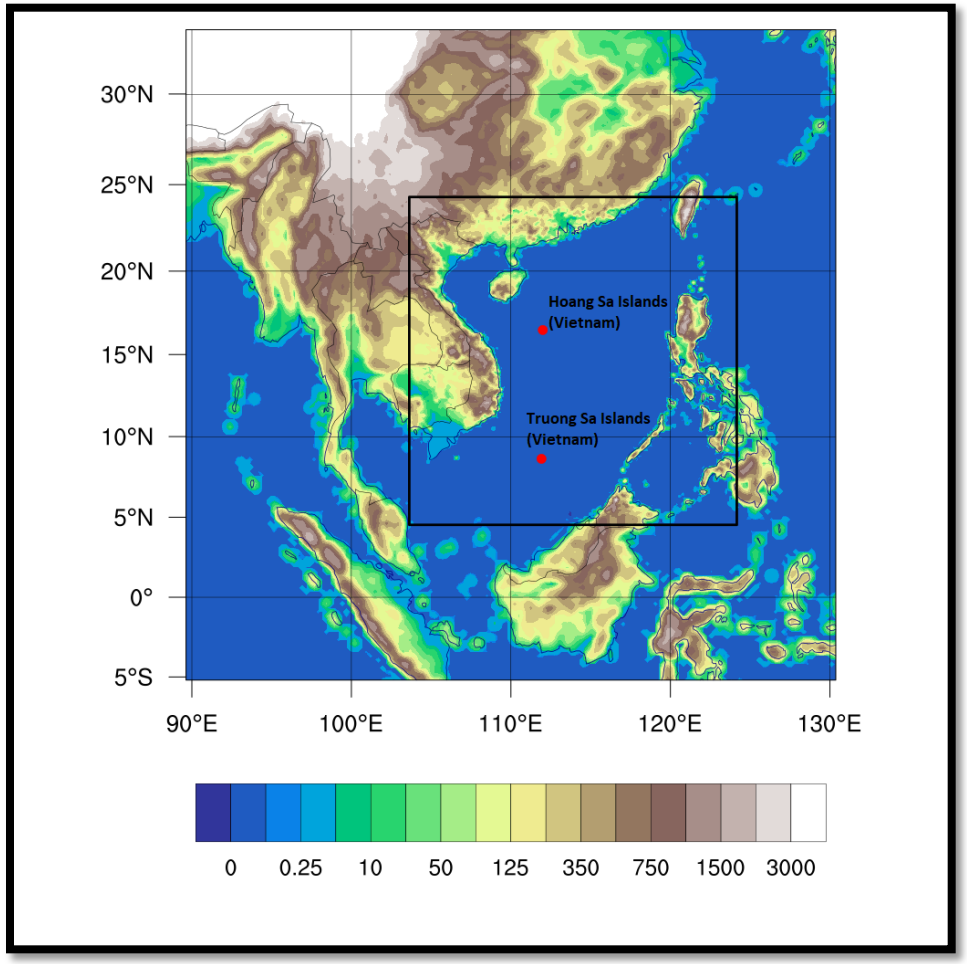
$$NFA: \begin{cases} 106°E - 120°E \\ 18.5°N - 23°N \end{cases}$$

Lei Wang (2008)

Data and methodology

The formation and intensification of tropical cyclones

	SINGLE DOMAIN	TWO WAY NESTED DOMAINS	
		Domain 1	Domain 2
	WRF_c	WRF_d01	WRF_d02
Horizontal resolution	27km	27km	9km
Domain of integration	90˚E - 130˚E 5˚S - 35˚N	90˚E - 130˚E 5˚S - 35˚N	104˚E - 124˚E 5˚N - 25˚N
No. of horizontal points	164×164	164×164	247×247
Vertical resolution (sigma levels)	28	28	28
Time step	135	135	45
Physics	- Microphysics Lin et al. Scheme. - Dudhia scheme for short wave radiation and RRTM scheme for long wave radiation. - 5-layer thermal diffusion scheme. - MM5 surface layer. - Cumulus parameterization Kain-Fritsch scheme. - Yonsei University (YSU) planetary boundary layer.		

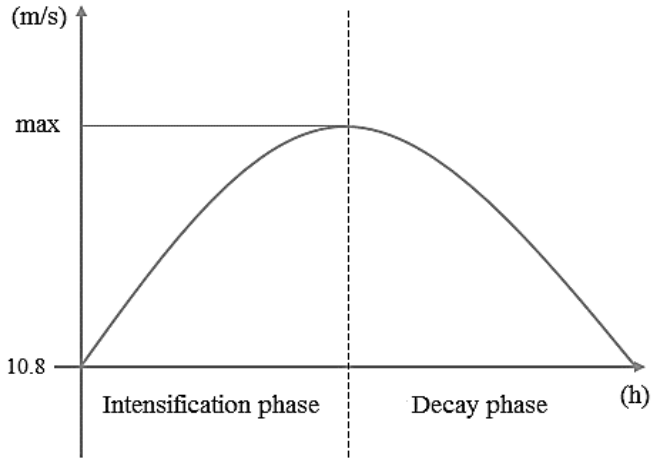


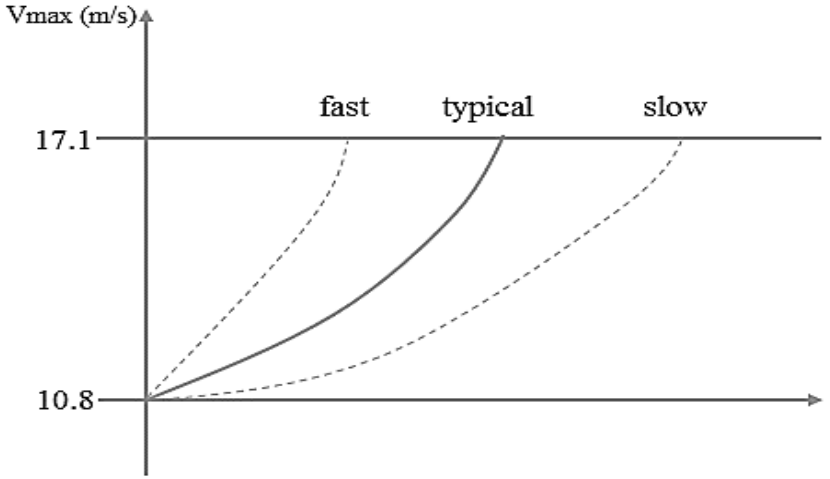
Identification of the center of the tropical cyclones

- The location of the minimum SLP is limited in the finding extreme domain as described above.
- The local maximal points of 10m-level wind speed are in 4° radius circle around the predicted center_with the value of above 10.8m/s

The formation/intensification of the tropical cyclones

$$\Delta t = t_F - t_O$$





The formation/intensification of the tropical cyclones

Table: *The 11 selected tropical cyclones information following VNCHMF (2013 - 2016)*

NO.	CATEGORY	NAME	THE FORMATION TIME		INITIAL LATITUDE	INITIAL LONGITUDE	DURATION DAYS
	undeveloped tropical cyclones						
1	TD		00Z 18/07/2013		13.3	114.5	2
2	TD		00Z 10/08/2013		12.3	117.2	1.875
3	TD		00Z 06/09/2014		15.3	117.4	1.5
4	TD		06Z 23/06/2016		12.0 – 13.0	117.5 – 118.5	3
5	TD		00Z 13/10/2016				
6	TD		00Z 03/11/2016		7.5	114.0	2.25
	developed tropical cyclones						
7	TS	Storm no. 8 (baoso8)	00Z 16/09/2013		16.0	114.0	2.875
8	TS	Hagibis	00Z 13/06/2014		18.8	116.0	10
9	TS	Vamco	00Z 13/09/2015		15.0	113.5	2.5
10	TS	Mirinae	00Z 25/07/2016		17.0	117.5	3
11	TS	Rai	06Z 11/09/2016		12.8	114.2	2

Ensemble forecast of the tropical storms intensity and track

- The set of data used is from tropical storms in five storm seasons in 2009, 2010, 2011, 2012 and 2013. The total number of experiments is 199 from 30 tropical storms that affect the Vietnamese region. The global data is taken in NCEP with the resolution of 1˚×1˚.
- 3 methods: Breeding of Growth Modes (BGM), Local Ensemble Transform Kalman Filter (LETKF) and nested domains for WRF simulations.

- **Super-ensemble techniques from the members of breeding methods**

25 initial fields from a NCEP initial field.

The prediction data in the period from 2009 to 2011 as dependent data to contribute to the super-ensemble equations.

Eqs from independent data are the tropical storms in 2012 and 2013.

- **Super-ensemble techniques from the members of Local Ensemble Transform Kalman Filter (LETKF)**

15 initial fields.

Numerical simulation from WRF with initial fields was created by the data from 00Z at storm date in the Bien Dong sea from 2009 to 2013.

The predicted data from 2009 to 2011 were used to build the super-ensemble equations with 15 members.

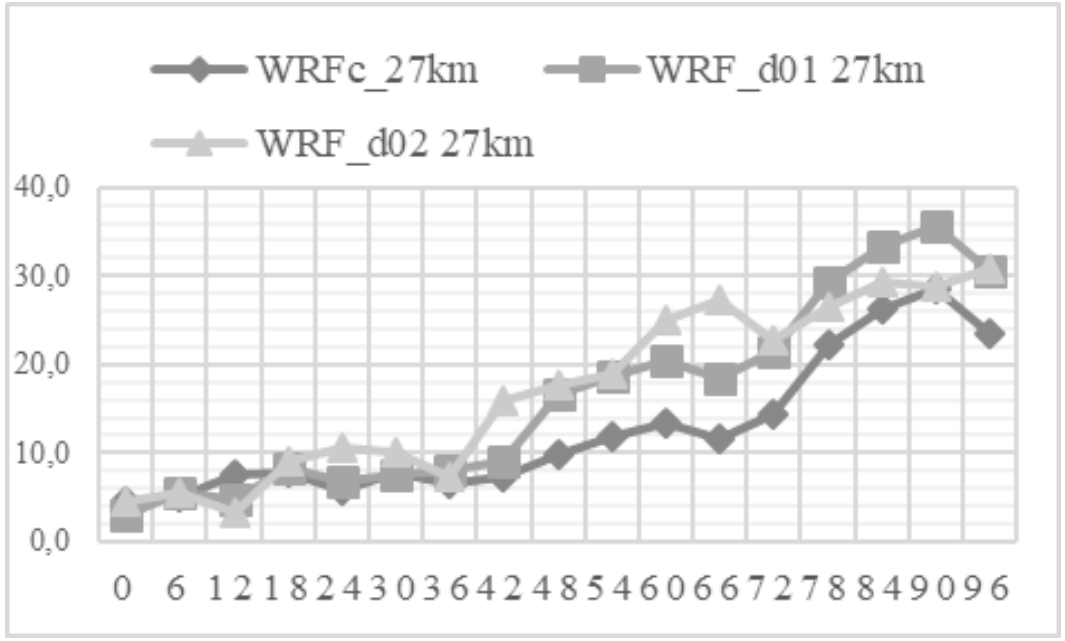
Eqs are examined on the independent data in 2012 and 2013.

- **Super-ensemble techniques from WRF-NEST**

The formation of the tropical cyclones

The formation of the tropical storm Hagibis

- The influence of the resolutions is not significant.
- In general, it increases with time.
- The WRF_d02 is larger than the others with the maximum of 12.2m/s at the 66h forecast.
- The tropical cyclone in this case is deepening.
- tropical depression stage: only 48h
- tropical storm stage: only 78h



	Genesis time	Lat	Lon	Genesis time error (h)	Distance (km)
Best - track	00Z 13/06/2014	116	18,8		
WRF_c	00Z 12/06/2014	110,3	17,7	-24	614,9
WRF_d01	18Z 12/06/2014	110,3	17,5	-24	620,0
WRF_d02	18Z 11/06/2014	113,5	16,4	-30	376,5

Analyzing of all the selected modeling tropical cyclones

- Using of nested domain with finer resolution does not enhance the forecasting skill in the formation time of tropical cyclones
- The using of nested domain can narrow the gap between the 2 observed and forecasted tropical cyclone centers.

	WRF_c	WRF_d01	WRF_d02
Mean formation time error	-14	-20	-18
Mean formation distance error	471,5	450,3	269,9

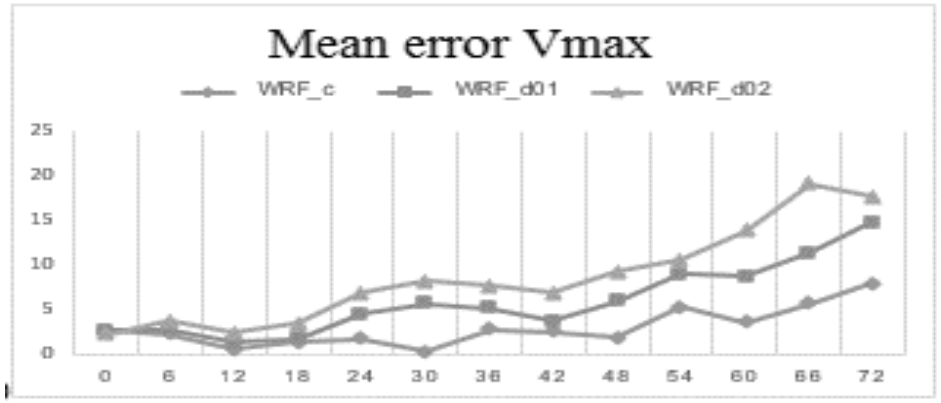
The intensification of the tropical cyclone

Developed tropical cyclones

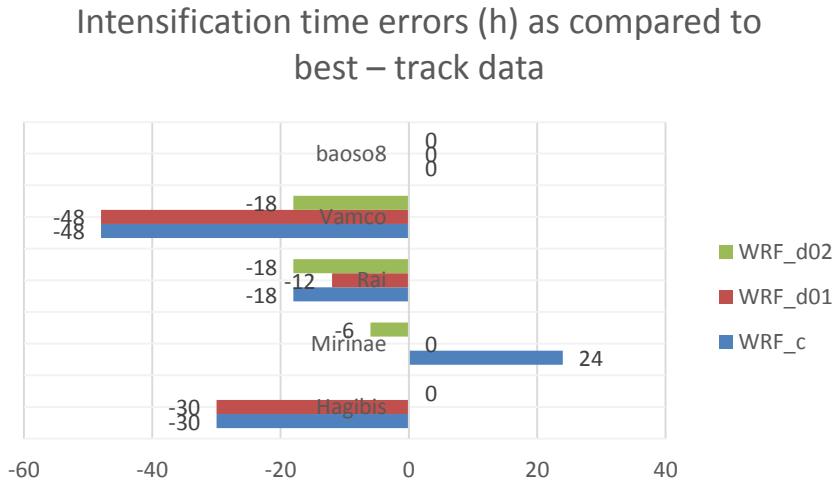
(WRF_d02) 9km nested domain deepen faster than in other coarse 27 km resolution domains.

WRF_c is relatively more accurate tropical cyclones with lower mean errors of about 2.9m/s in average.

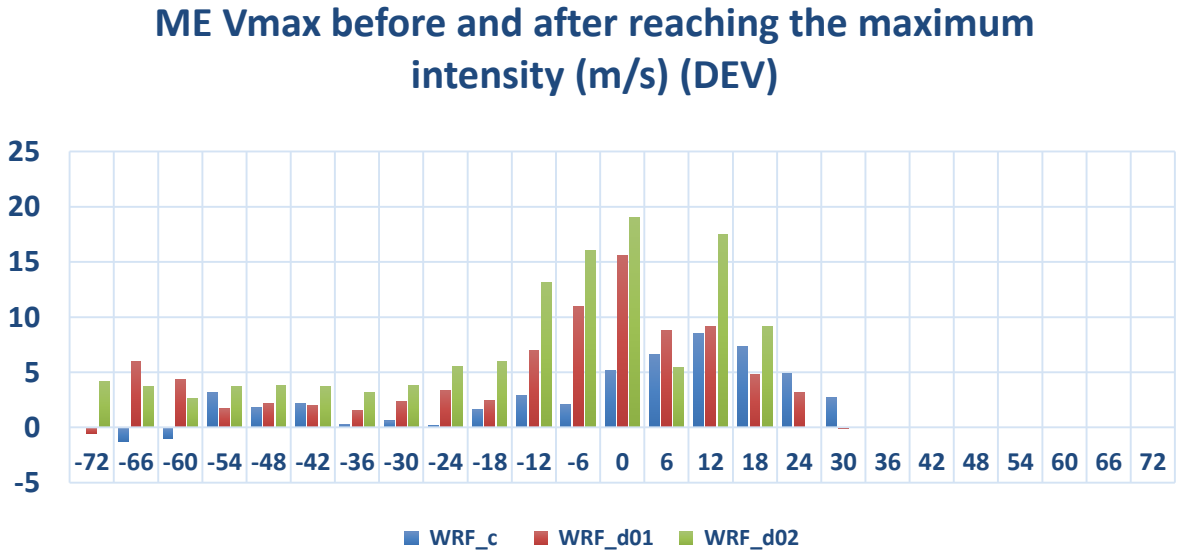
=> The non-nested domain shows more closed tropical cyclones to those in the best-track data.



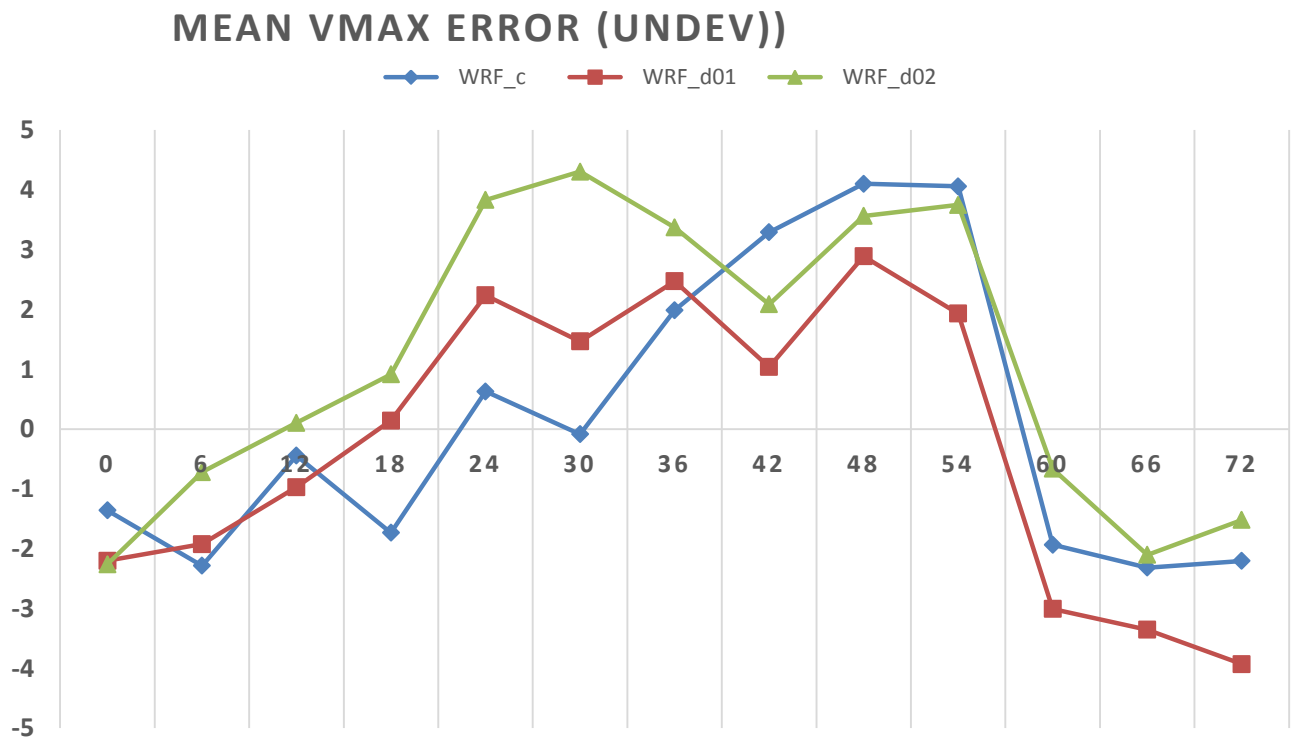
Time variation of the mean error in 5 developed tropical cyclones intensity in maximum wind speed at 10m (Vmax) (m/s)



Intensification time errors (h) of the 5 developed tropical cyclones

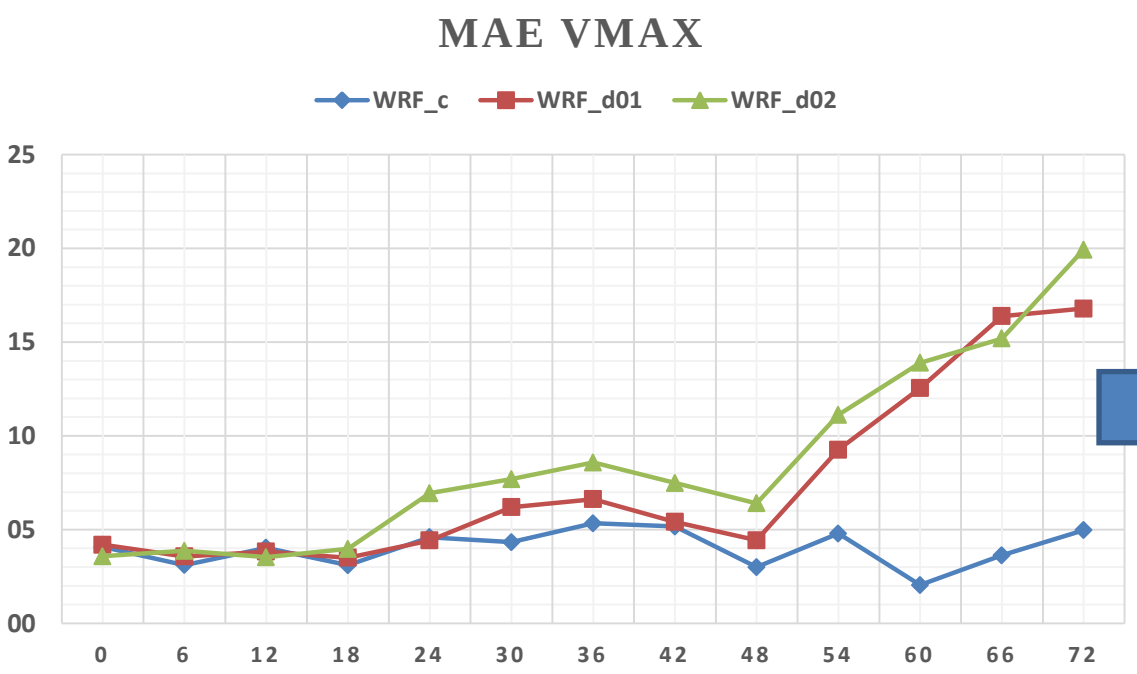


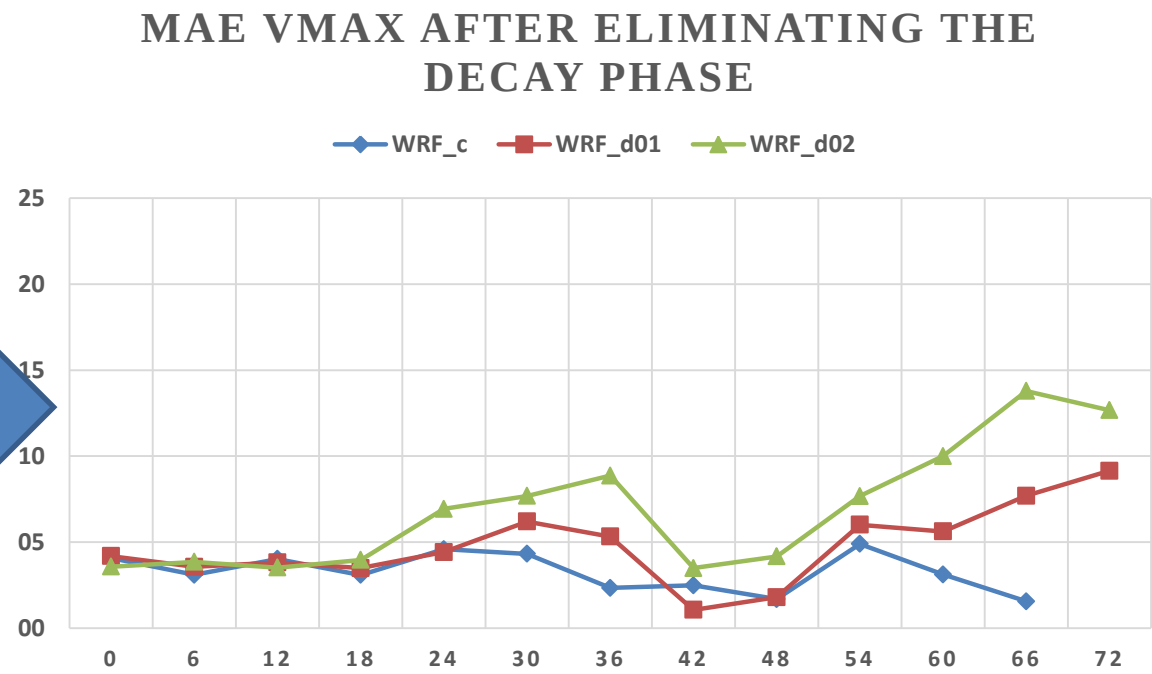
Undeveloped tropical cyclones



Mean error Vmax of the undeveloped tropical cyclones

Analyzing of all the selected modeling tropical cyclones





Mean absolute error of Vmax on 11 tropical cyclones

Ensemble forecast of the tropical storms intensity and track

Mean absolute error in ensemble forecast for storm track and intensity by the 3 methods (BGM, LETKF, WRF-NEST) for 2012 and 2013

(Pmin: Minimum sea level pressure, Vmax: maximum velocity, MPE: Mean position error)

Time (h)	WRF-NEST				BREEDING				LETKF			
	No. of cases	MPE (km)	Pmin error (hPa)	Vmax error (m/s)	No. of cases	MPE (km)	Pmin error (hPa)	Vmax error (m/s)	No. of cases	MPE (km)	Pmin error (hPa)	Vmax error (m/s)
24	33	174	9	5.7	33	125	28	25	33	140	12	9
48	33	212	7	3.6	33	197	19	33	33	180	13	13
72	33	260	8	4.1	33	265	23	34	33	280	10	12
96	27	325	16	7.2	27	275	14	22	27	260	7	8
120	20	378	9	3.3	20	354	8	17	20	375	4	5

Ensemble forecast combined from 3 methods

- Method 1 (PA1):

choose the method with the minimum of mean distance be the result for predicting the storm center location.

intensity: analyzed the average of the MAE in the 3 methods, then picked the method which shows the minimum of MAE in intensity

Time (h)	Dependent data (km)	Independent data (km)	Optimal data (km)
24	68	131	125
48	95	176	180
72	158	228	260
96	193	250	275
120	238	321	354

Position errors (km) of 2-dimensional regression method for predicting tropical storm track on dependent and independent datasets PA2 and optimal method PA1

Predicting storm track: BGM
Predicting VMAX: WRF-NEST
WRF-NEST: suitable for predicting Pmin up to 3 days forecast
LETKF is more suitable for predicting Pmin from 4 to 5 days forecast.

Ensemble forecast combined from 3 methods

- Method 2: Applying the 2-dimensional regression method to the prediction data set with BGM, LETKF and WRF-NEST methods as shown in Table (PA2)

Improved from 2 to 5 days forecast

Time (h)	Dependent data (km)	Independent data (km)	Optimal data (km)
24	68	131	125
48	95	176	180
72	158	228	260
96	193	250	275
120	238	321	354

Position errors (km) of 2-dimensional regression method for predicting tropical storm track on dependent and independent datasets PA2 and optimal method PA1

Conclusions

- After removing the decay phase, we have improved the accuracy in numerical prediction, especially in the nested finer domain.
- With BGM, LETKF and WRF-NEST methods: at 1, 2, 3, 4 and 5 days forecast

the mean distance errors are 125, 180, 260, 275 and 354km

the Vmax errors are in turn 5.7, 3.6, 4.1, 7.2 and 3.3m/s

the Pmin errors are 9, 7, 8, 7 and 4hPa.

Reference

- Lei Wang (2008): A thesis on the study of tropical cyclogenesis over the South China Sea, *Hongkong University of Science and Technology*.
- J. S. Blackerby, Accuracy of Western North Pacific tropical, Naval Postgraduate School, 2005.