The Influences of Low-Frequency Vorticity on Tropical Cyclone Formation Based on Systematic Model Simulations

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Outline

1. Introduction
2. Environment of Tropical cyclone (TC) formation in the western N Pacific (WNP)
3. Diagnosis of systematic simulation results
4. Cumulus scheme experiments
5. Summary

…it is far more natural to assume that genesis is a series of events, arising by chance from … of further …

TC Formation is a stochastic process

…the climatological and synoptic conditions do not directly determine the process of genesis, but … affect the probability of its happening.

(Ooyama, 1982)

Any deterministic nature of TC Formation???

Time

MJO, Kelvin waves,

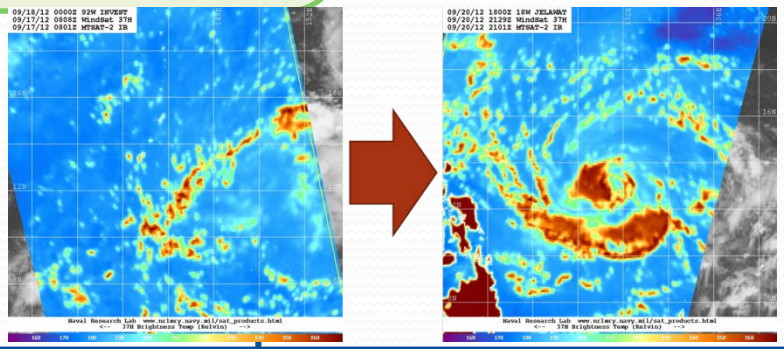
- (… 2006; Gall et al., 2010)

Synoptic Environments, Easterly Waves

- (Briegel and Frank, 1996; Ritchie and Holland, 1999; Dunkerton et al., 2009; Montgomery et al., 2009; Wang et al., 2010a, b; Montgomery et al., 2010; Chang et al., 2010; Lin and Lee, 2011; Wang et al., 2011)

VHTs, MCVs

- (Ritchie and Holland,1997; Simpson et al., 1997; Hendricks et al., 2004; Montgomery et al., 2006; Houze et al., 2010)

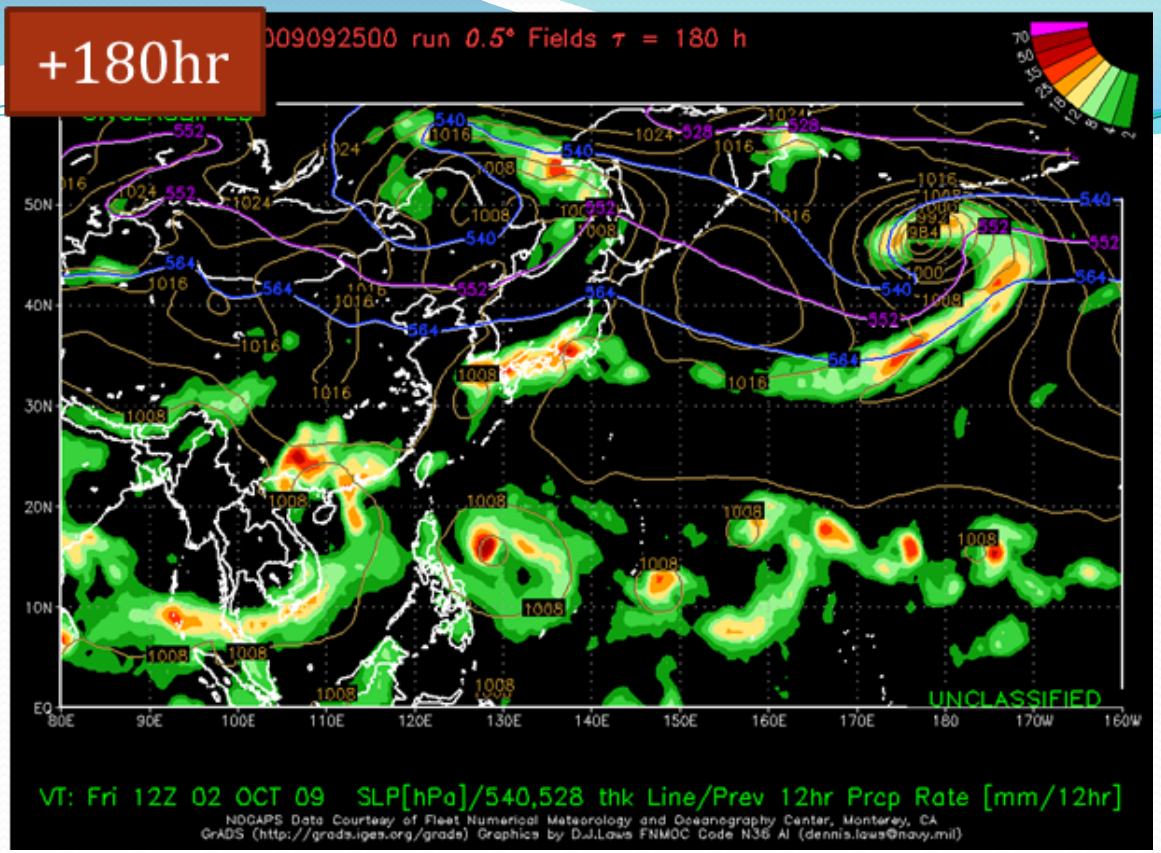


~100 km

~1000 km

~5000 km

Scale



The 32-day ensemble forecast model of ECMWF was able to resolve the formation of most TCs (2009–2010), but some of the weak and short-lived TCs were missed.

- (Elsberry et al., 2010, 2011; Tsai and Elsberry, 2013; Elsberry et al., 2014)

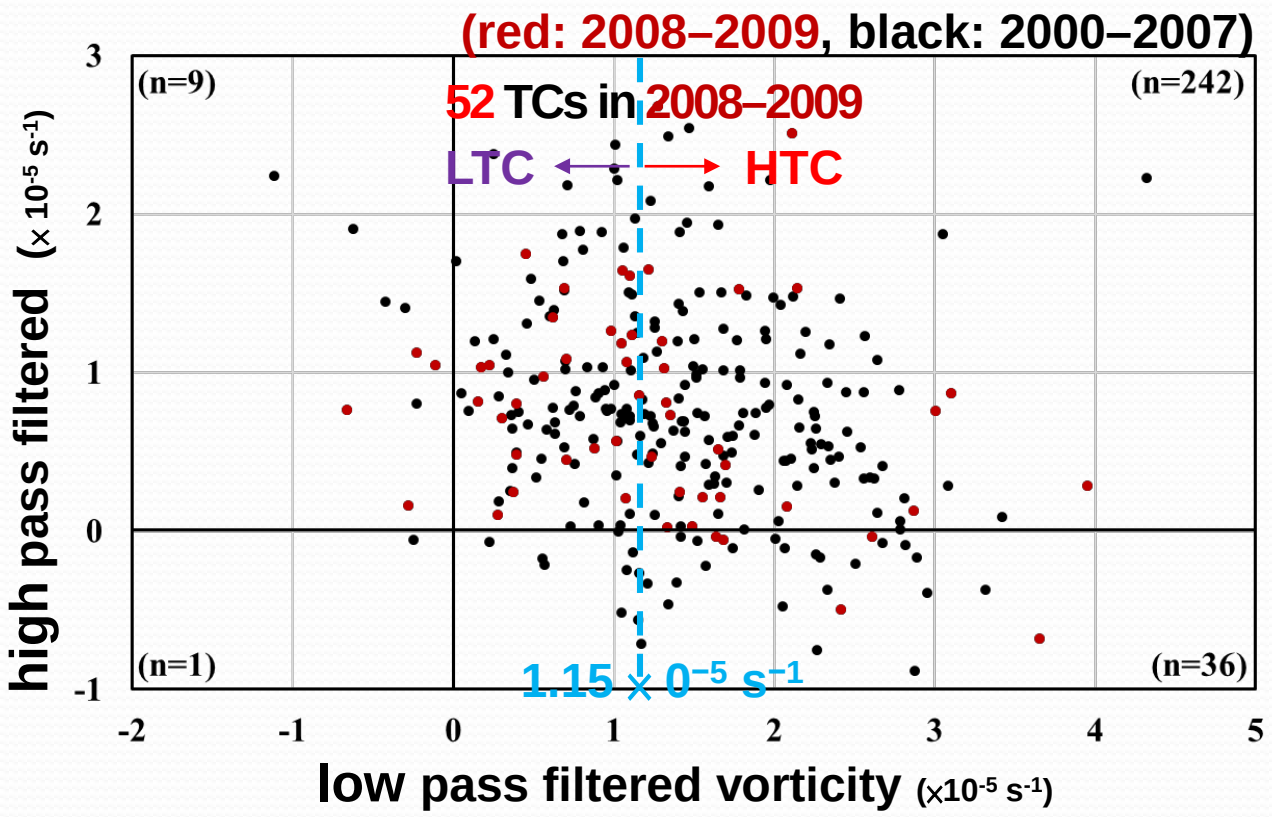
To understand the capability of a numerical model to simulate (forecast) TC formation properly under different environments*[1]?

(*[1] Ritchie and Holland, 1999)

Background 850-hPa vorticity of pre-TC disturbances

The 10-day*[2] low pass and high pass filters are applied to NCEP_FNL (2000-2009) data to obtained low/high pass filtered winds. - (*[2] Wu et al., 2013)

Use filtered winds to compute 850-hPa mean vorticity within 5° radius of the pre-TC disturbance in the WNP at 24-48h before the formation of TC (Vmax ~ 25kt).



TCs with Higher low-frequency vorticity, 26 HTCs - HTCs
TCs with Lower low-frequency vorticity, 26 LTCs - LTCs

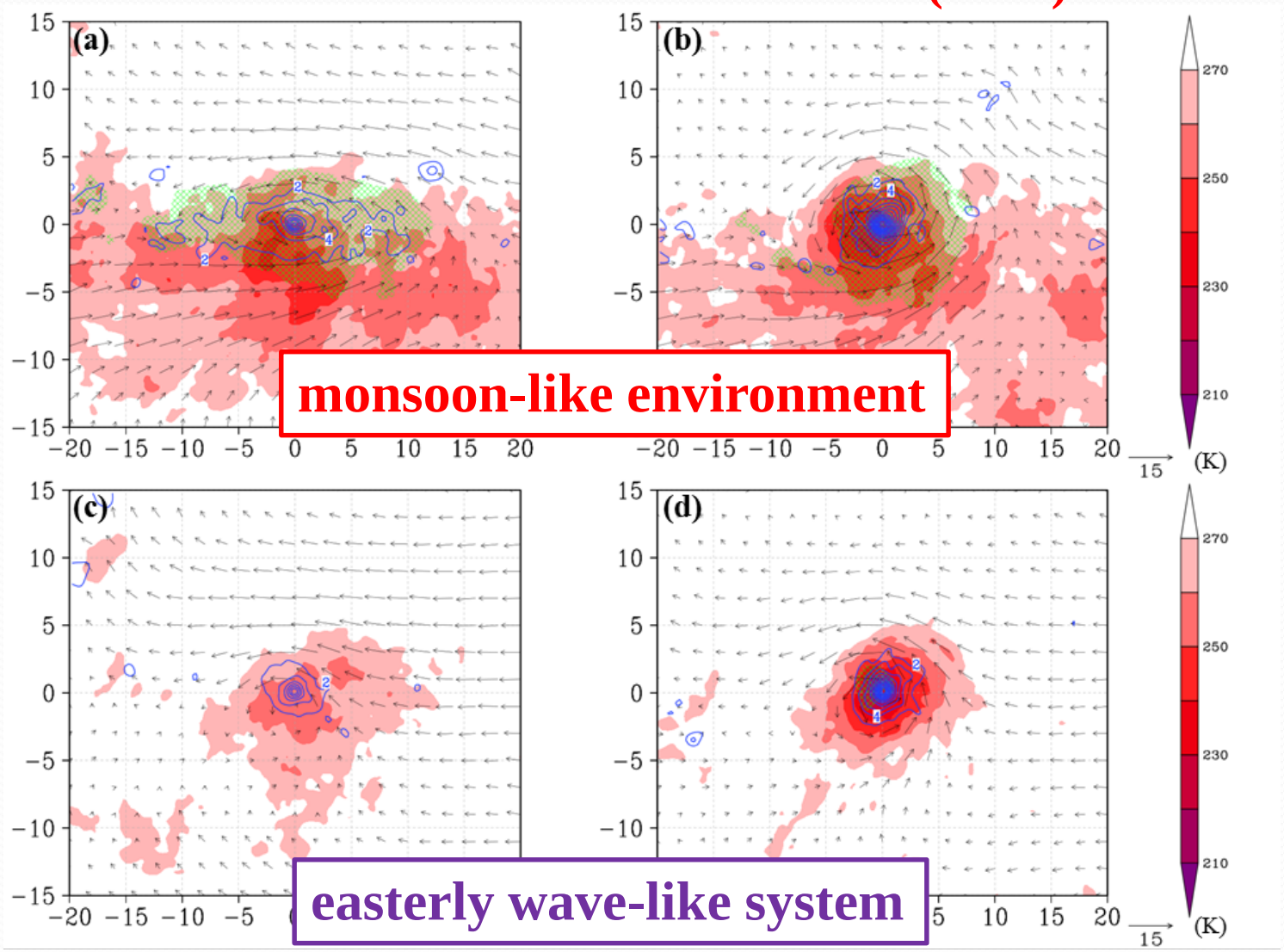
Synoptic environments during TC formation (850hPa)

HTCs

TCs with higher low-frequency vorticity

LTCs

TCs with lower low-frequency vorticity



Vorticity (~2x10^{-5}s^{-1}), wind vectors and cloud top temperature

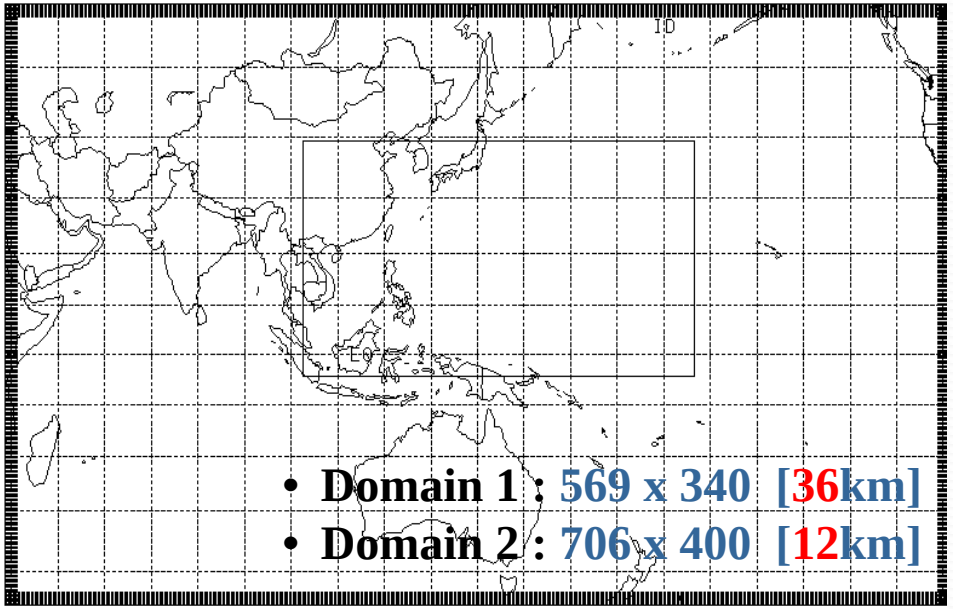
Model setup of systematic numerical simulations

Use WRF V3.2.1 to simulate
all 52 TCs in 2008 and 2009

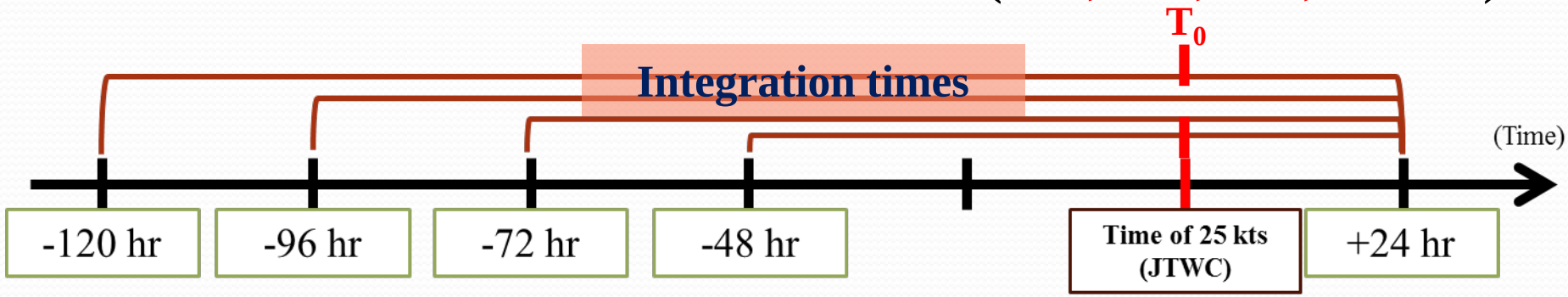
Cloud microphysics: WDM6
Cumulus scheme: Kain-Fritsch
PBL Physics : YSU

-Kieu and Zhang, 2008; Chiao and Jenkins, 2010; Wang et al., 2010; Crosbie and Serra, 2014; Li et al., 2014; Xu et al., 2014

Initial conditions:
NCEP_FNL &
EC_YOTC (available only in 2008-2009)



Simulations started at 4 distinct initial times (-48h, -72h, -96h, & -120h)



For each TC: 2 (initial conditions) x 4 (initial times) = 8 members

416 runs

Criteria used to defined a model-simulated TC

Target period: -12 hr ~ +12 hr of 1st 25 kt (JTWC best track)

1. **Clear circulation center and max. vorticity center at 850 hPa**

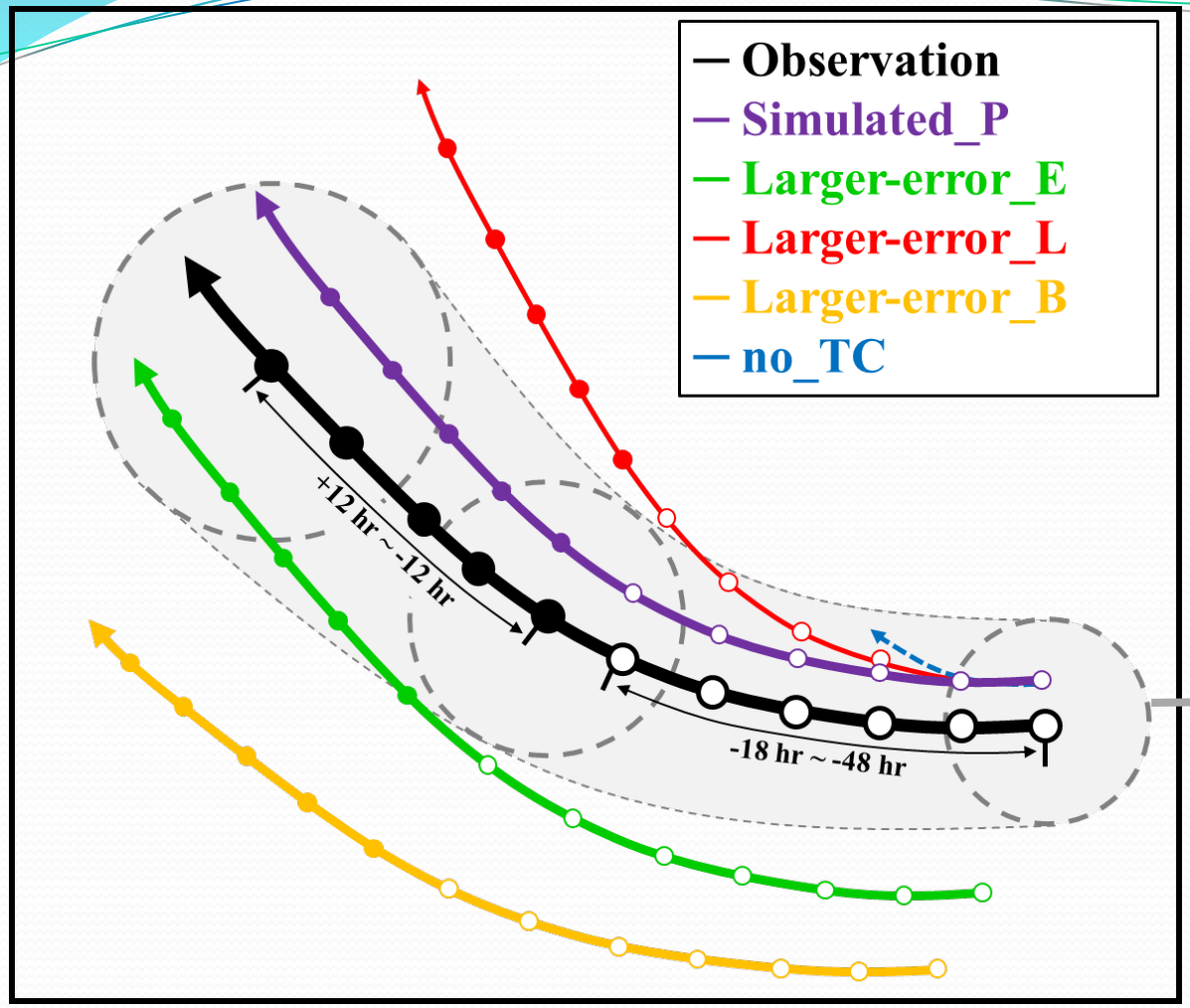
2. **Mean vorticity at 850 hPa:**
   - **> $7.9 * 10^{-5}$ s^{-1} inside 1.5°**
   - **> $3.8 * 10^{-5}$ s^{-1} inside 3°, or > $1.5 * 10^{-5}$ s^{-1} inside 5°**

     (mean – 1 x SD of 52 TCs in EC-YOTC data)

3. **Satisfy above criteria for 12 hours or longer**

Sugi et al., 2002; Chauvin et al., 2006; Yoshimura et al., 2006; Stowasser et al., 2007; Jourdain et al., 2011; Zhan et al., 2011

The classification of model simulated TCs



Dashed circle –
mean track error of all simulated TCs (varies with initial time)

-48h ~ 249 km,

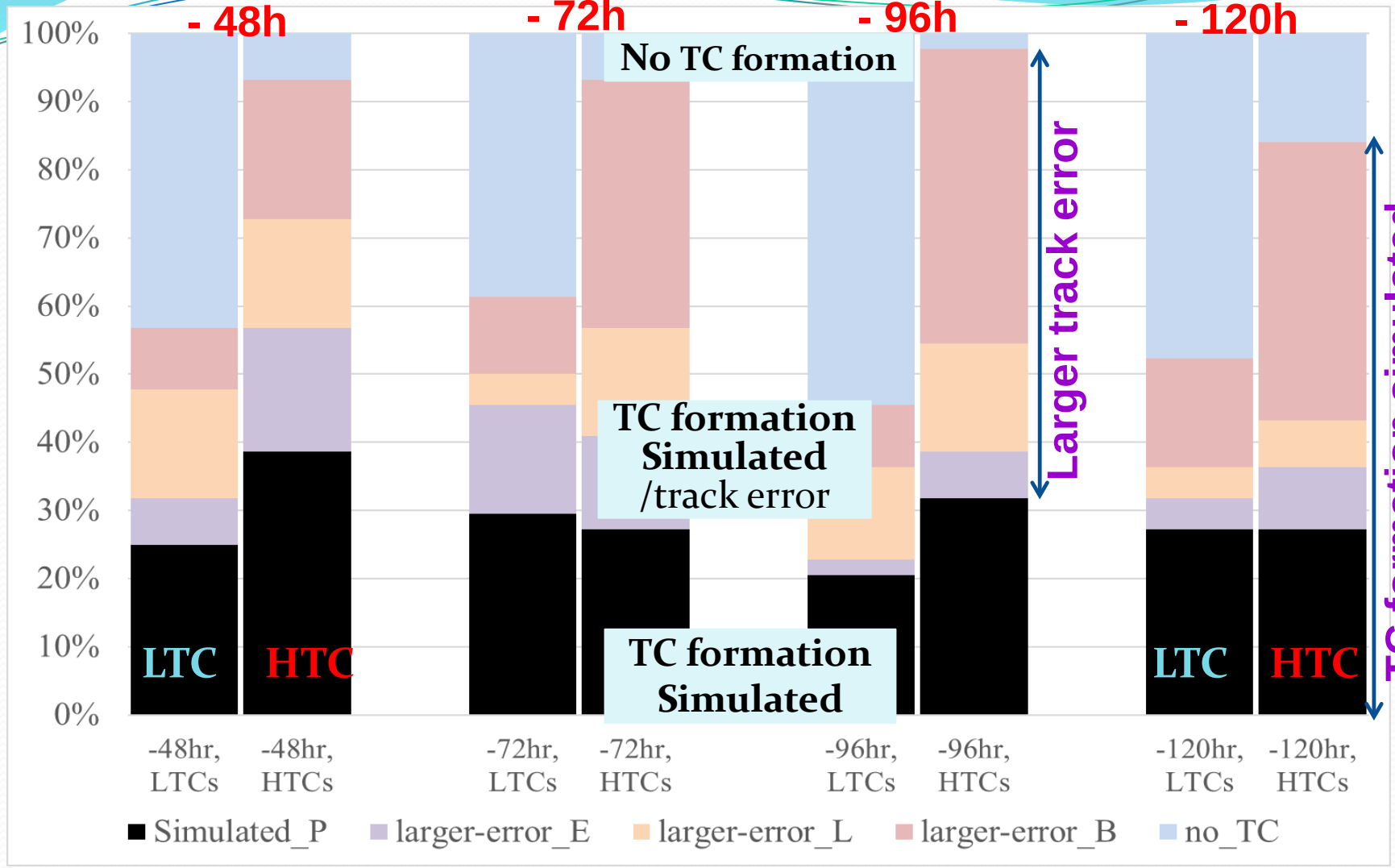
-72h ~ 301 km,

-96h ~ 441 km,

-120h ~ 600 km,

Classify all 416 simulations into 5 groups: no_TC, Simulated_P, large track error_E, large track error_L, and large track error_B

Percentages of five types of simulation results



Model is more capable of simulating the formation of a HTC, but w/larger location bias.
Model is less capable of simulating the formation of a LTC, but w/smaller location bias.

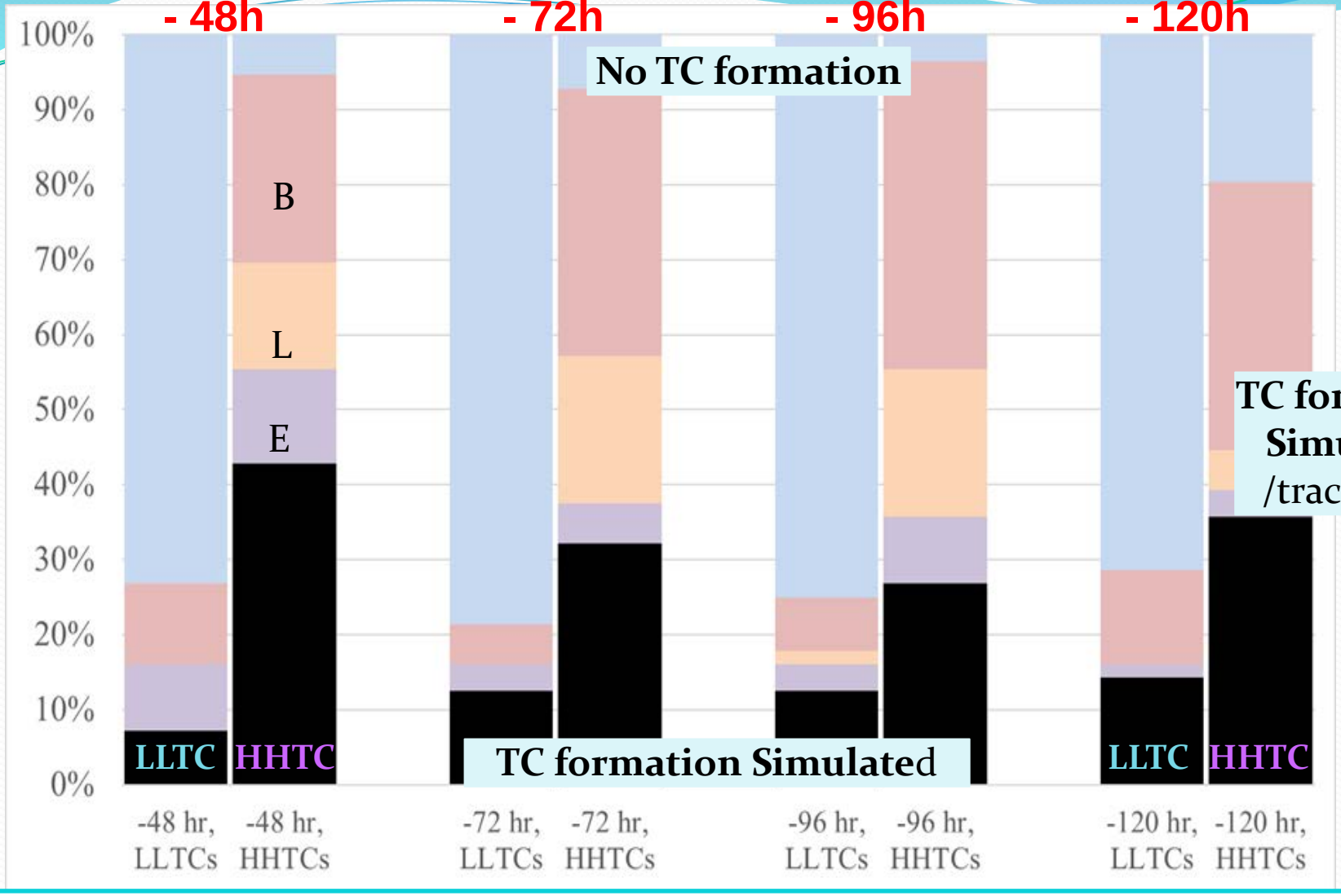
Results sensitive to the physics schemes used ?

- 14 extreme cases are selected to perform the sensitivity test.
  - 7 HTCs with Highst low-frequency vorticity (HHTCs):
    Halong (2008), Kalmaegi (2008), Fung-Wong (2008), Mekkhala (2008), Morakot (2009), Dujuan (2009), and Ketasna (2009)
  - 7 LTCs with Lowst low-frequency vorticity (LLTCs):
    Nakri (2008), Nuri (2008), TS14W (2008), Maysak (2008), Haishen (2008), Noul (2008), and Lupit (2009)
- The cumulus scheme appears to be the most important one, 4 cumulus schemes are used in the test (CU_EXP).

Expt	TC#	Cumulus Parameterization	PBL Physics	Micro-physics	Long-wave radiation	Short-wave radiation	Initial condi-tions	Initial times	Member Number per TC
CTL	52	Kain-Fritsch (new Eta)	YSU	WDM6	RRTM	Dudhia	EC-YOTC & NCEP-FNL	-48, -72, -96, -120 hr	8
CU_EXP	14	Kain-Fritsch (new Eta), Betts-Miller-Janjic, Grell-Devenyi ensemble, and Grell 3D ensemble							32

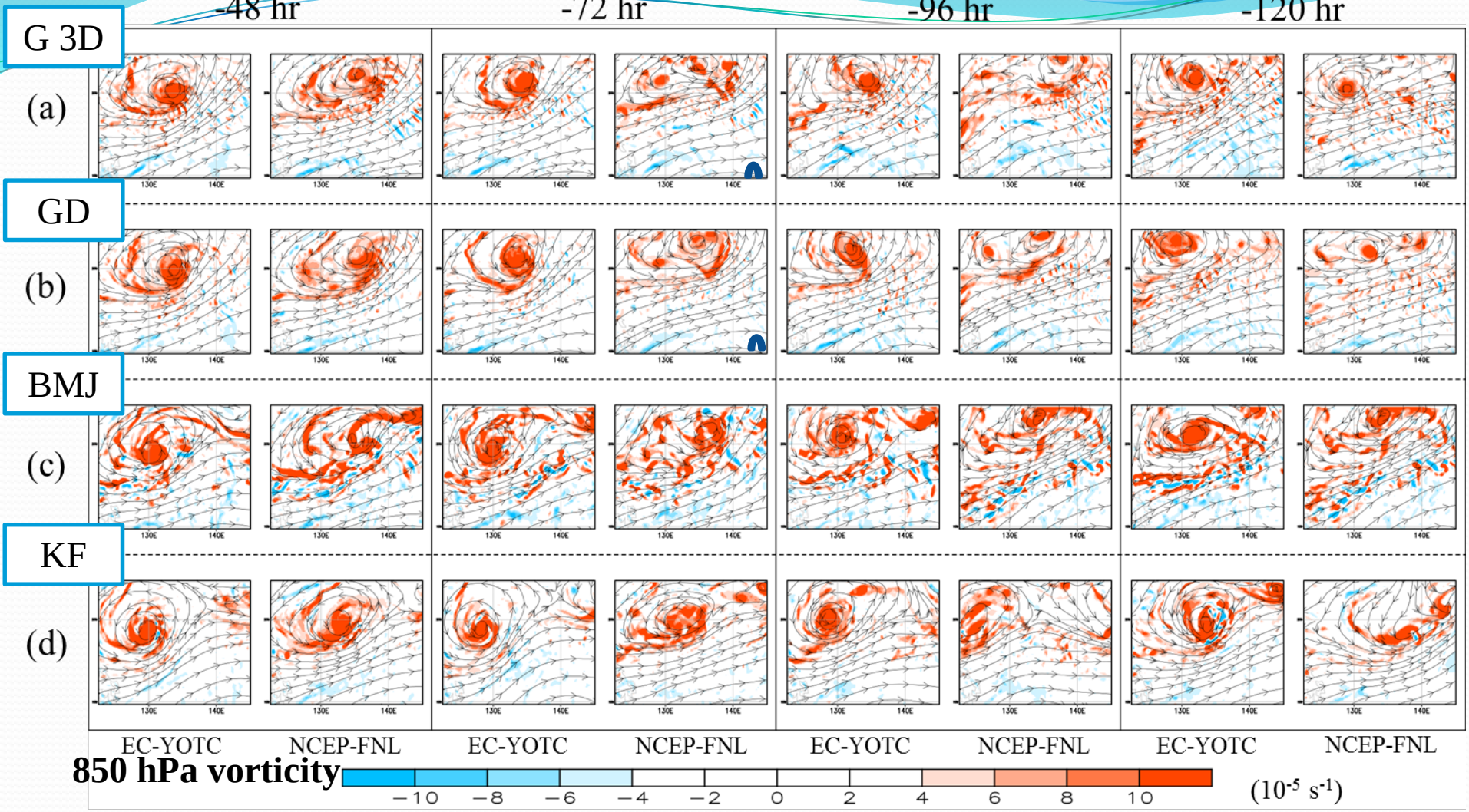
(376 more runs, totally 792 runs)

Cumulus experiment



The relative proportions of five simulation results for HHTCs and LLTCs are similar to those for HTCs and LTCs

Simulated results of a HHTC (Dujuan, 2009) at T_0



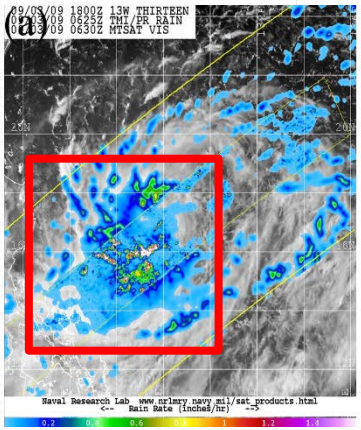
Grell 3D ensemble
Grell-Devenyi ensemble
Betts-Miller-Janjic
Kain-Fritch

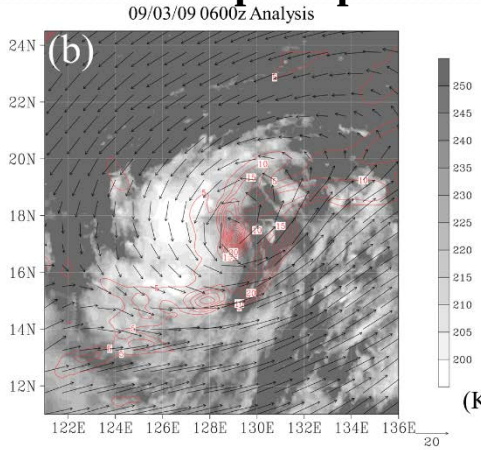
Most simulations (30/32) have "TC formation", but some of them have large track errors.

Observed vs. simulated convective features (Dujuan, 2009)

HHTC (T_0-12)

Cloud top temperature (K, shaded, gridsat data) &

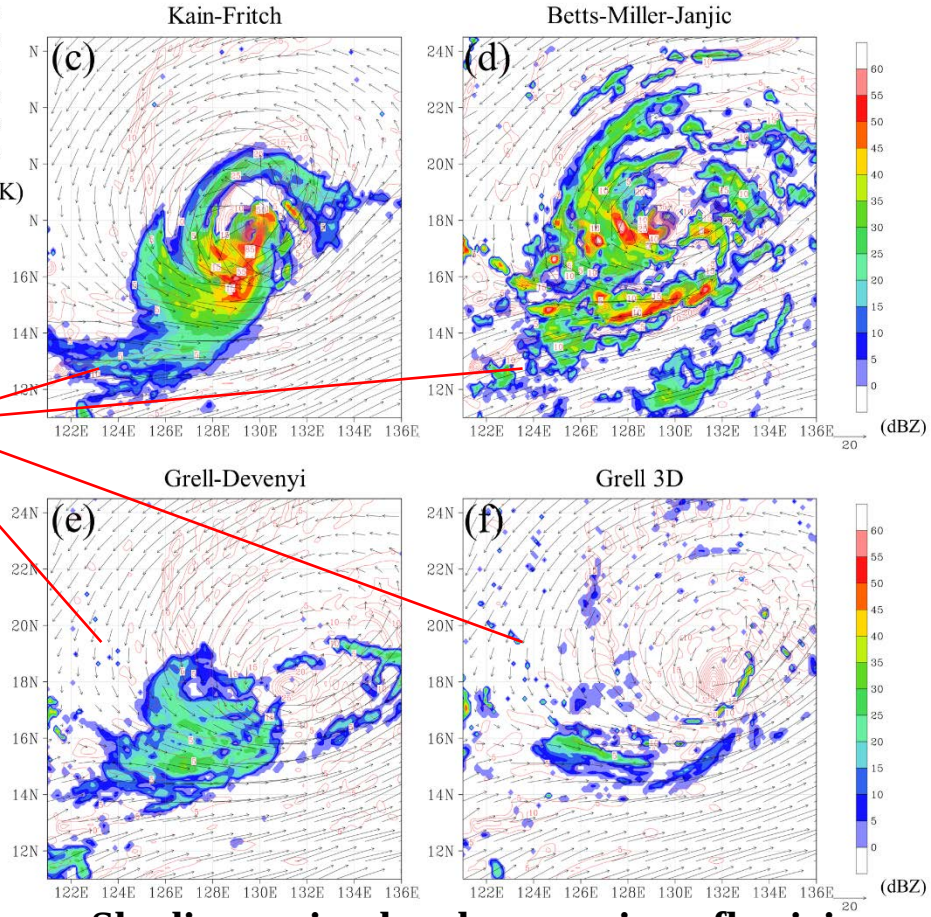




Hourly rain rates (mm h^{-1}) at 0625 UTC 03 Sep 2009
(TMI/PR from NRL's website)

850-hPa winds and vort at 0600 UTC 03 Sep 2009 (> 5 × 10^{-5} s^{-1}, red contours at 5 × 10^{-5} s^{-1} intervals)

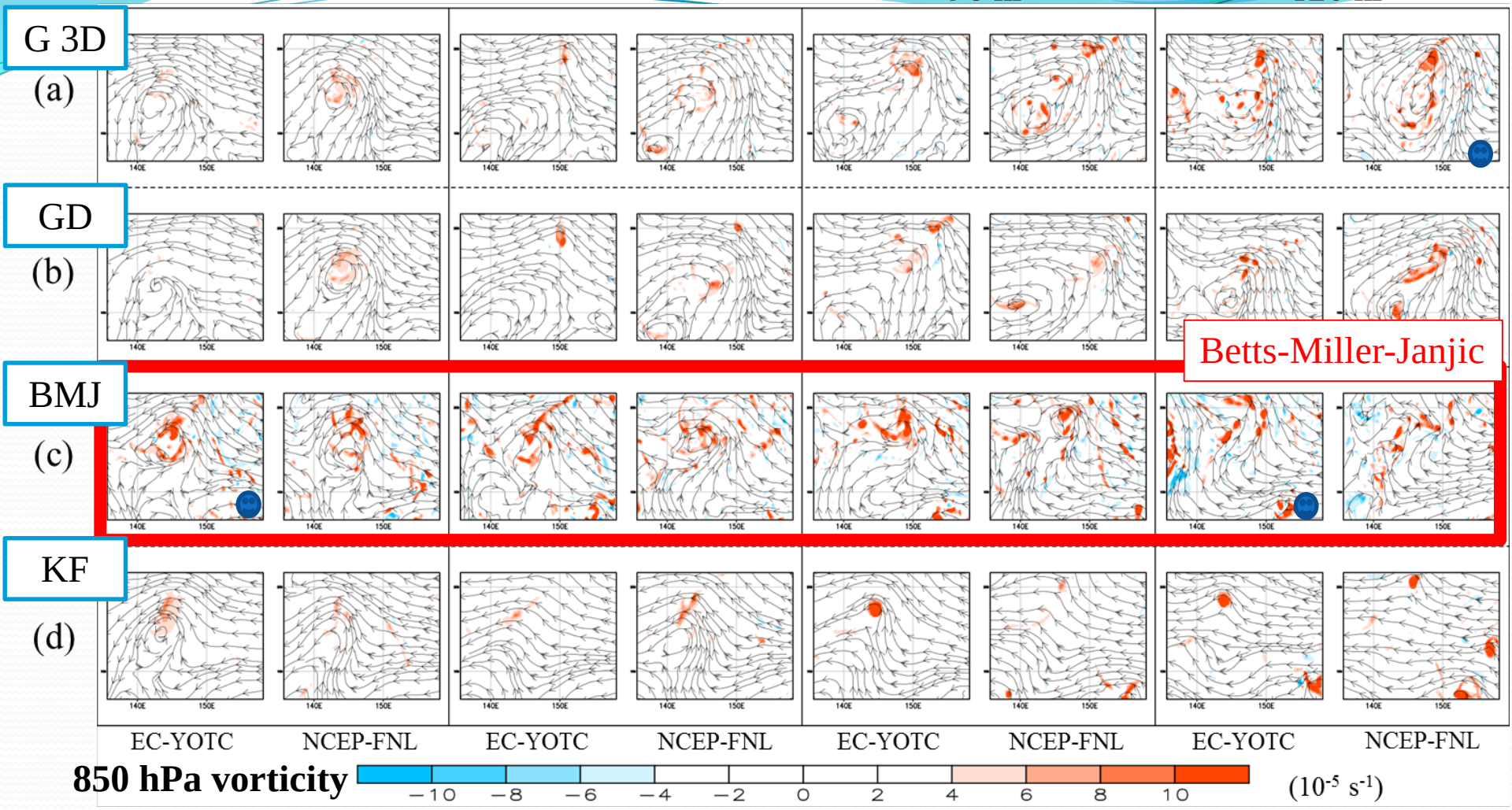
-48 hr / EC-YOTC



Shadings - simulated composite reflectivity (the maximum reflectivity at grid column)

- **Convection patterns similar to observation, but different in strength**
- **All have "TC formation", but with different track errors**
- **Whether TC will form or not seems to be not too sensitive to cumulus schemes for HHTC**

Simulated results of a LLTC (Nuri, 2008) at T_0



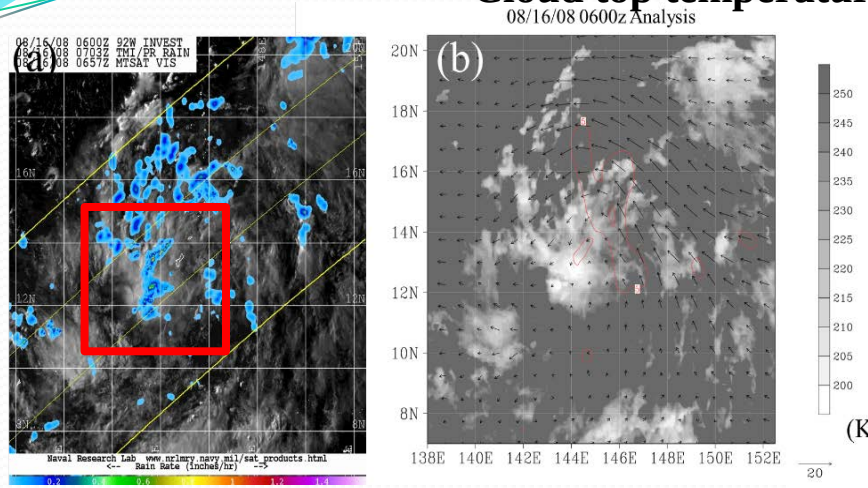
Grell 3D ensemble
Grell-Devenyi ensemble
Betts-Miller-Janjic
Kain-Fritch

Simulations using Betts-Miller-Janjic cumulus scheme generally have better cyclonic circulation and higher vorticity

Observed vs. simulated convective features (Nuri, 2008)

LLTC (T_0-12)

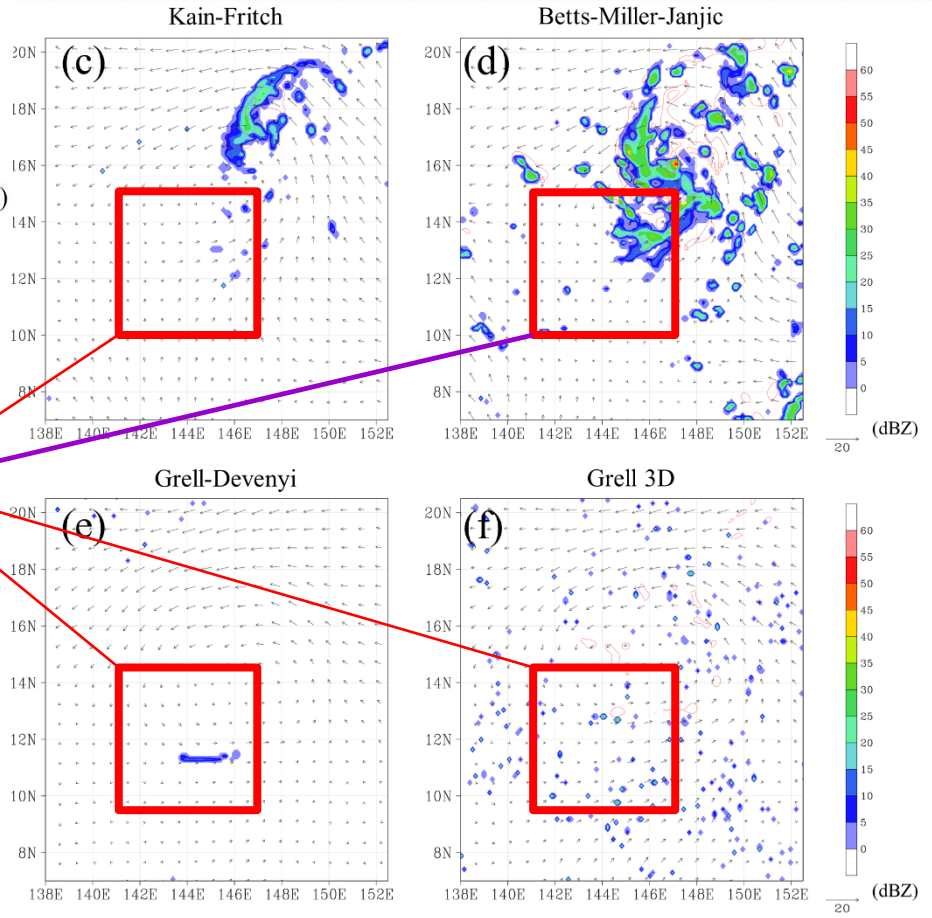
Cloud top temperature (K, shaded, gridsat data) &



Hourly rain rates (mm h^{-1}) at 0703 UTC 16 Aug 2008
(TMI/PR from NRL's website)

850-hPa winds and vort at 0600 UTC 16 Aug 2008
(> 5 × 10^{-5} s^{-1}, red contours at 5 × 10^{-5} s^{-1} intervals)

-48 hr / EC-YOTC



"TC formation" occurs only in simulations using BMJ scheme

Convection pattern is sensitive to the cumulus schemes used for LLTCs

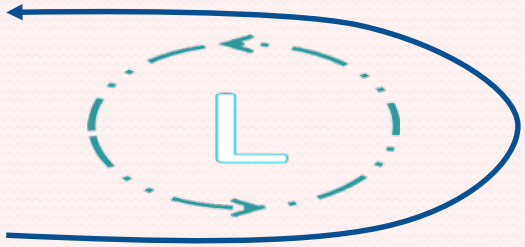
Shadings - simulated composite reflectivity (the maximum reflectivity at grid column)

Summary

Lower low-frequency vorticity

- easterly wave-like
- harder for TC formation (lower percentage)
- smaller track error
- Simulation results sensitive to the cumulus schemes

Higher low-frequency vorticity



- monsoon-like
- easier for TC formation (higher percentage)
- larger track error
- Simulation results not too sensitive to the cu schemes

The convection process (cumulus scheme) is not the key factor for TC formation in an environment with large low-frequency vorticity, but very important if the environmental low-frequency vorticity is small.

Conclusions (?)

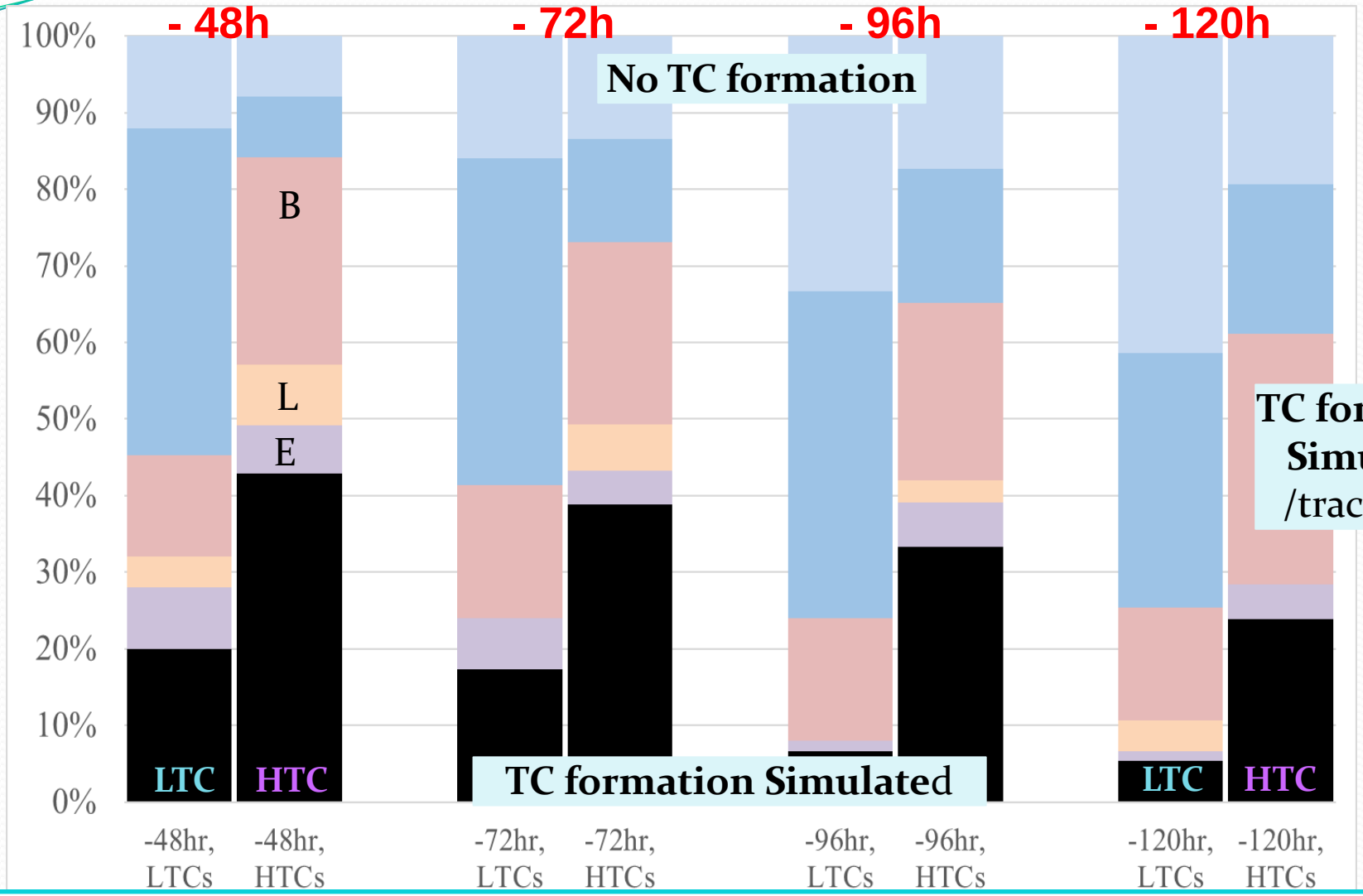
- **Under an environment (monsoon-like) with favorable condition, especially large vorticity, TC formation can be expected -- *deterministic nature of TC formation.***
- **But the timing and location of TC formation are affected by convective process -- *stochastic nature.***
- **Under a less favorable environment (easterly wave-like), convections play key role to TC formation -- *TC formation is more like a stochastic process.***

Need more studies to fully address this issue.

Thanks for your attention

TIGGE forecasts (ECMWF, NCEP, AMMC)

The THORPEX Interactive Grand Global Ensemble (TIGGE)



The relative proportions of five simulation results in TIGGE forecasts are similar to those for HTCs and LTCs

(red: non-formation, black: formation)