Is the Strom Circulation and the Large-Scale Flow in Quasi-Equilibrium

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Outlines

- Introduction
- NC2011 and NC2014
- Realtime & Hindcast setup
- Typhoon Jelawat(2012) Hindcast with NC2014
- Hurricane Ana(2014) Realtime Forecast with NC2014
- Other TC applications
- Conclusions

Introduction

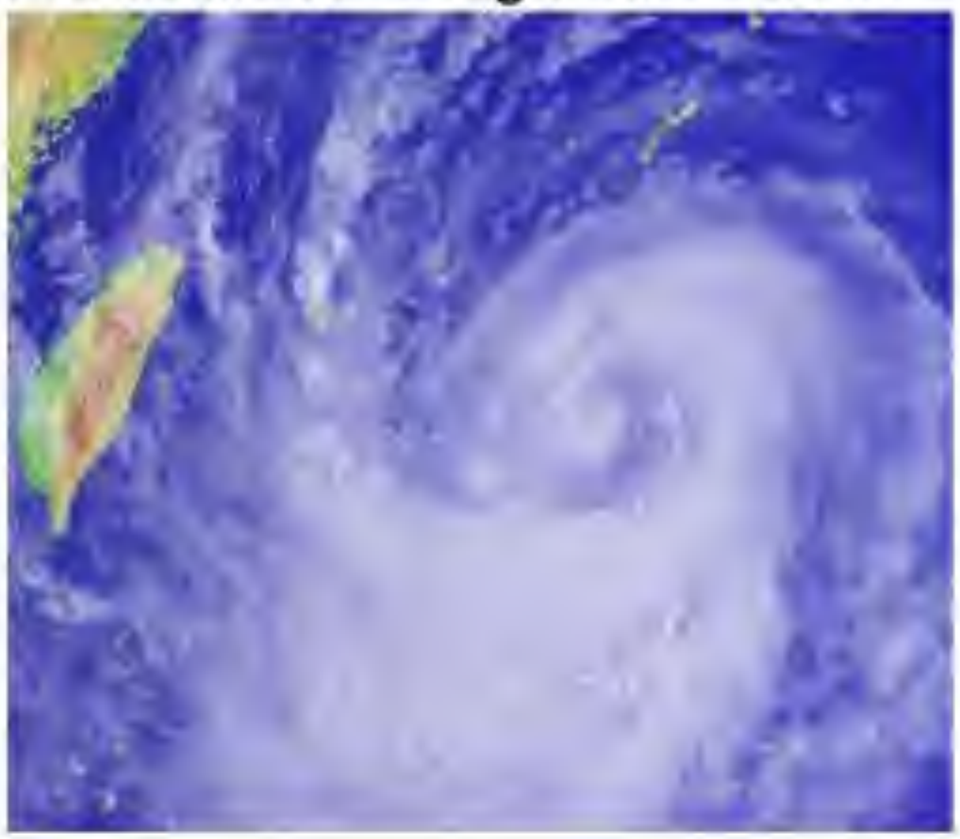
- Nguyen and Chen (2011) (hereafter NC2011) developed a new dynamical tropical cyclone initialization method through model cycling runs. They hypothesized that the tropical cyclone structure was closely related to the environmental fields that the storm was embedded in.

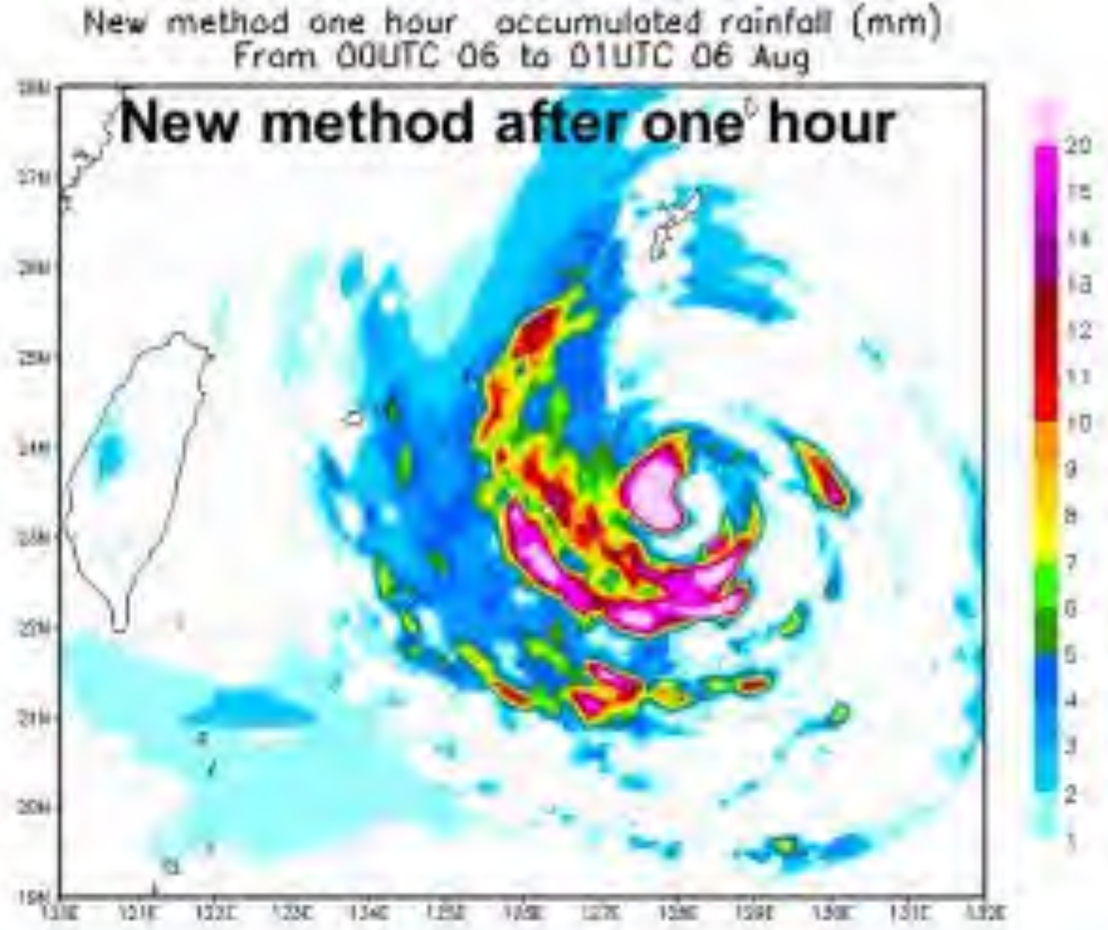
- Assumption: The TC structure at the initial time is a function of environment conditions including SST, land surface properties, environment winds and other environment meteorological variables.

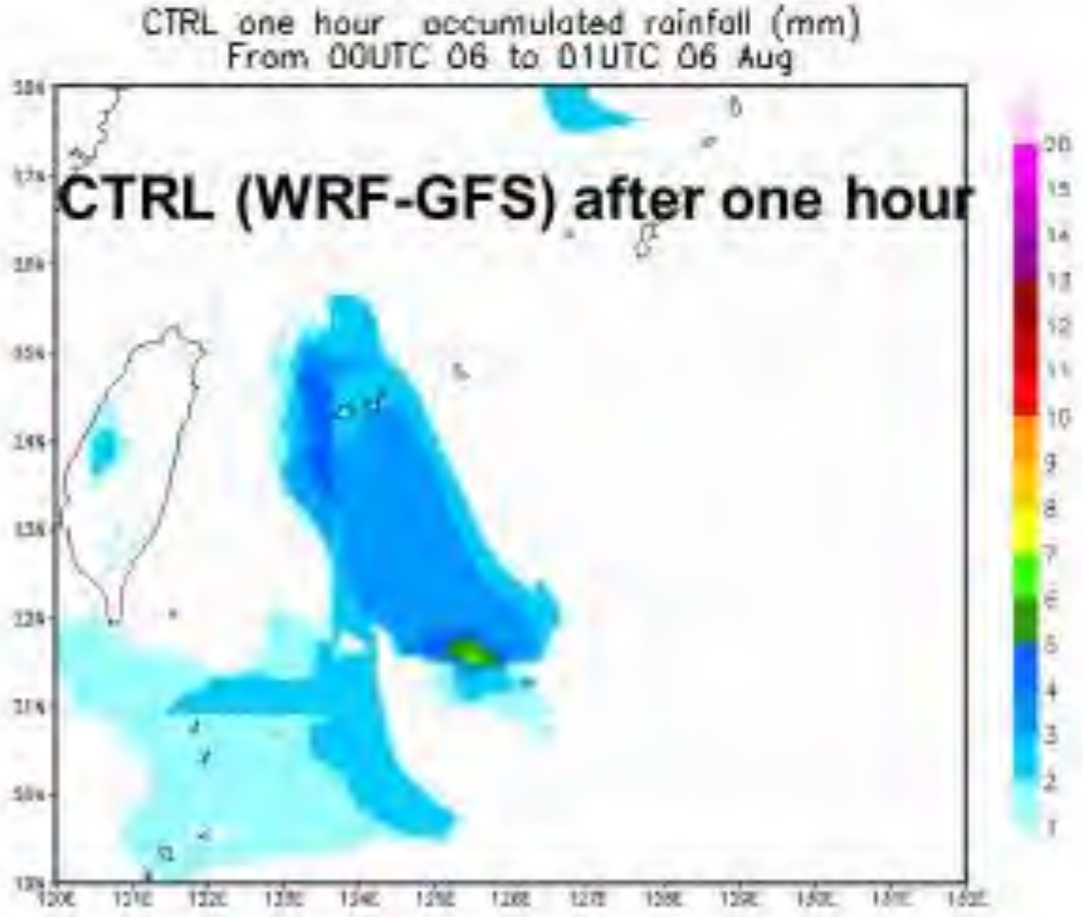
- In a short period of time (<1 hour), the TC moves, however, its structure does not change significantly.

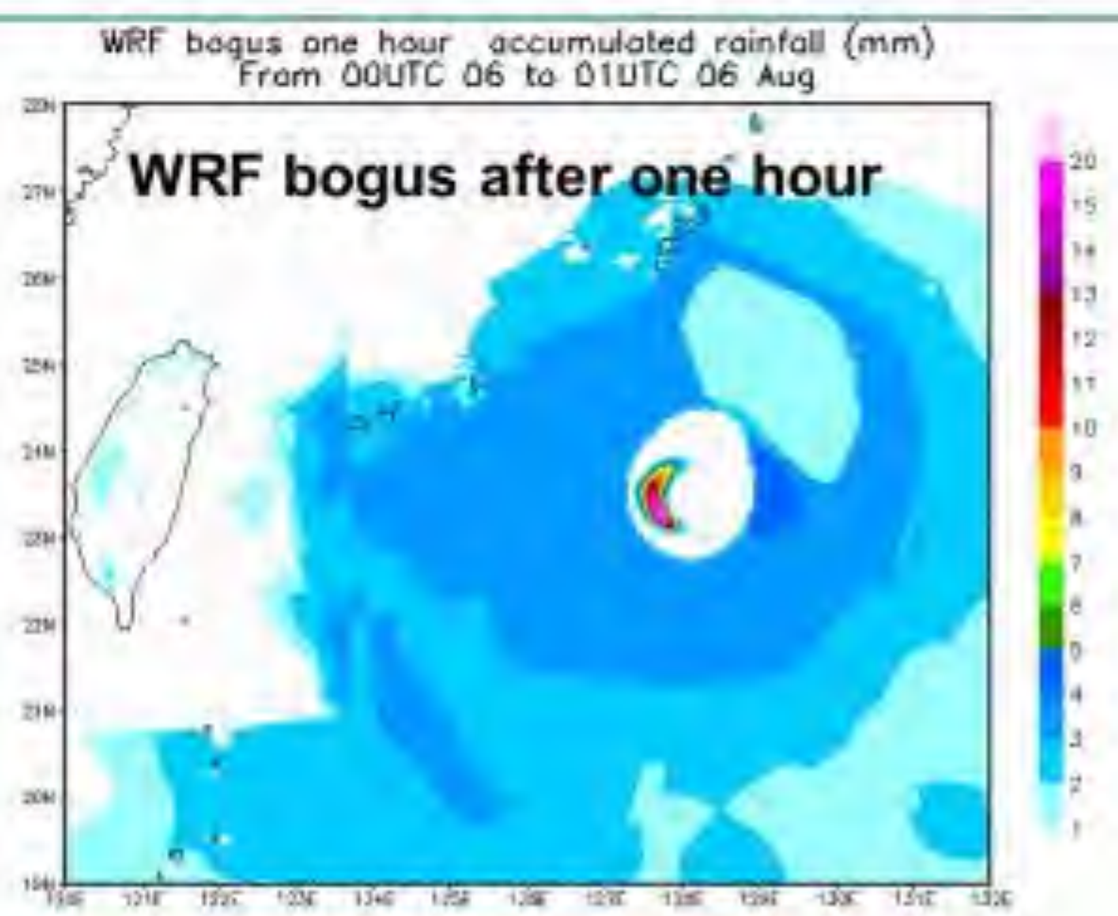
- Integrate model for a short period of time (dt=1hour), the vortex structure at t=t0+dt is used to construct vortex structure at the initial time (t=t0) for the next cycle run. The initial TC in the model is well adjusted to the environment after a number of cycle runs.

VIS satellite image at 01UTC

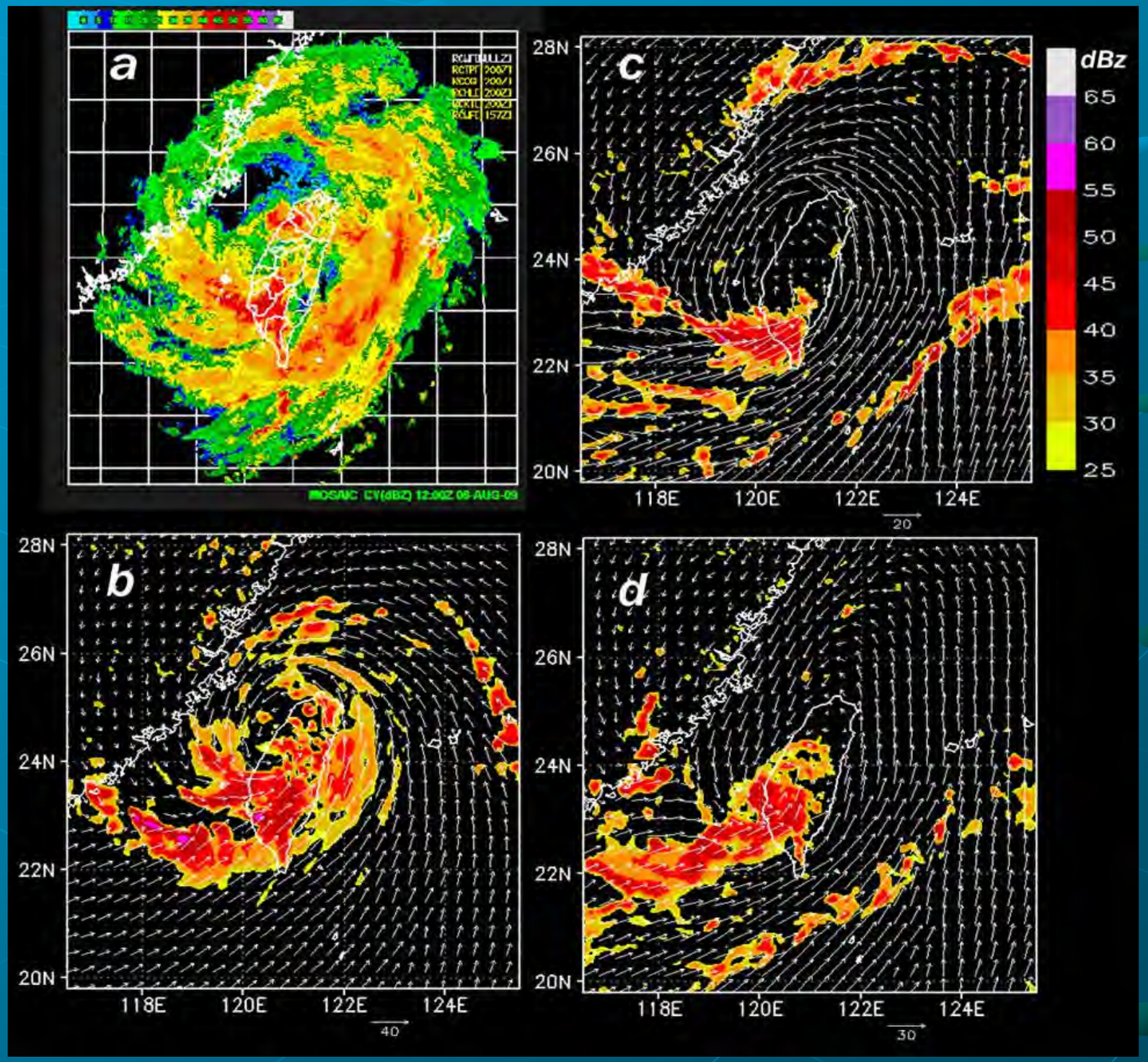








Horizontal distribution of radar reflectivity (dBz) at 1200 UTC 8 August, 2009 for (a) observed, and simulated radar reflectivity of over 25 dBz for (b) the NT, (c) CTRL, and (d) WB runs after 54 h of integrations. Note: Localized heavy rainfall also depends on simulated storm structure



Spin-up Setup

- WRF model V3.3.1 + TC initialize scheme (Nguyen and Chen. 2011)
- 18km(121x121x38), 6km(205x205x38)
- IC & BC : NCEP 0.5 deg GFS Analysis (For 2007 - 2013 cases), NCEP 1.0 deg FNL (For 2003, - 2006 cases).
- Physics: WSM6s(mp), RRTM(lw), Dudhia(sw), YSU(pbl), Grell(cu)

- **NC2011 scheme has considerable skills in reproducing the observed structure and intensity in the model initial conditions.**
- **“9” type TC structures are usually associated with the low level SW monsoon flow in early summer.**
- **“6” type TCs usually occurred in the late season with the NE monsoon flow.**
- **Some intense storms may undergo eyewall replacement cycle during the mature stage under weak shear and symmetric upper-level outflow channels.**
- **The NC2011 scheme produces reasonable good initial intensity and structure for 18 storms after spin-up (2003 - 2013). (Chen et al. 2014 *SOLA*)**

- Nguyen and Chen (2014) (hereafter NC2014) updated the original NC2011 method with inserting an extra warm core. The number of cycles could be reduced about 1/2 - 1/3 times. This would be useful for realtime TC forecast applications.

- The magnitude of the maximum temperature anomaly was dependent on the best track minimum surface pressure (P_{min}) using a linear relationship for typhoons over the northwestern Pacific which suggested by Velden et al. (1991) [$(dT)_{max}$ = (1013. 2 - P_{min} - 2 2.)/11.8].

- The warm core had a radius of 60km with a Gaussian weighting function (Kidder et al. 2000) in both the horizontal and vertical direction.

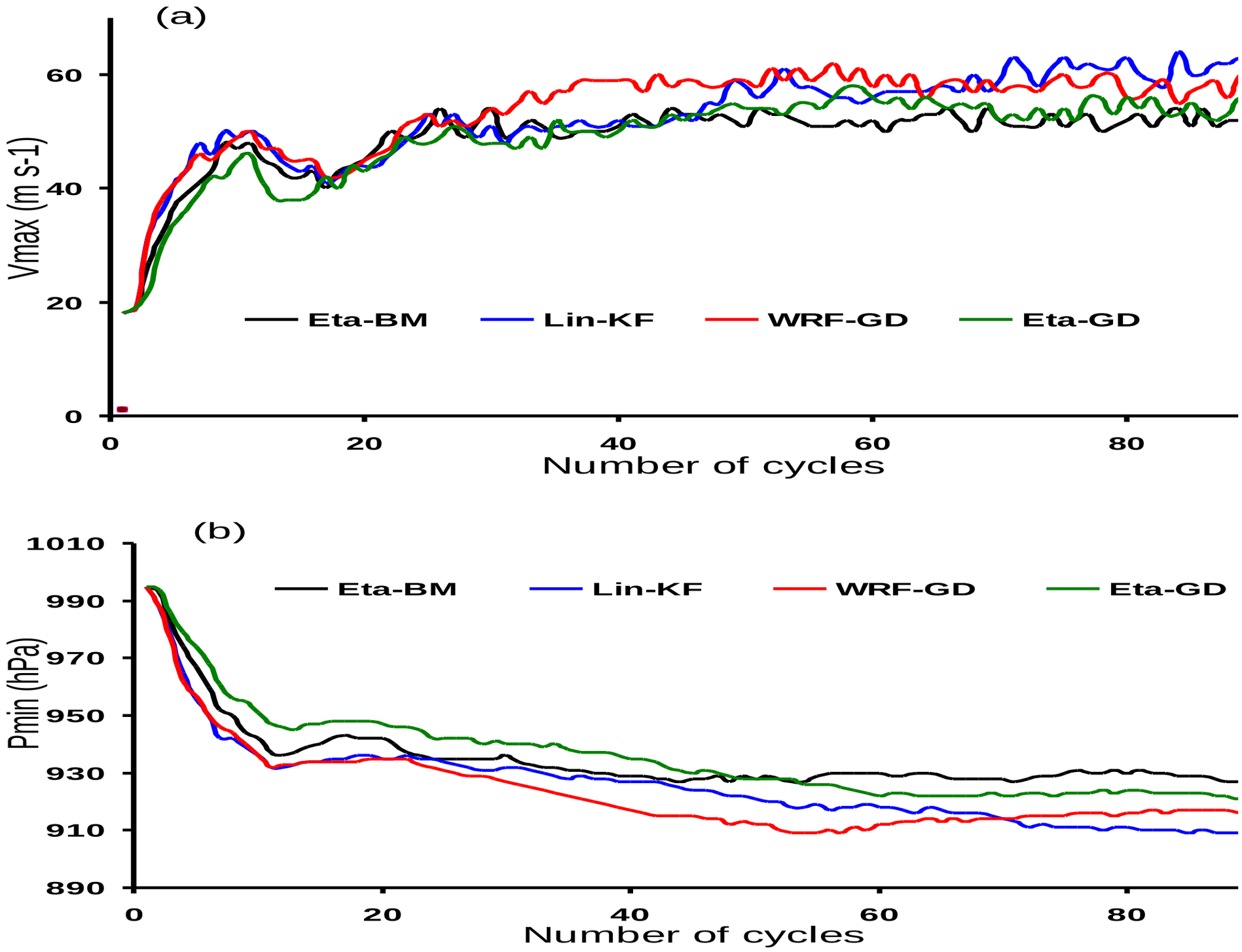


Figure 4. The changes of (a) maximum wind speed (m s^{-1}) and (b) minimum SLP (hPa) with number of cycle runs for WRF-GD (red), Eta-BM (black), Lin-KF (blue), and Eta-GD (green) sensitivity test runs.

NC2014 applied the updated version of the TC initialization scheme and showed significant improvements in the track and intensity TC forecasts during the first 48 h of model runs for four landfalling TCs, which occurred in the South China Sea in 2006, as compared with the runs without TC initialization

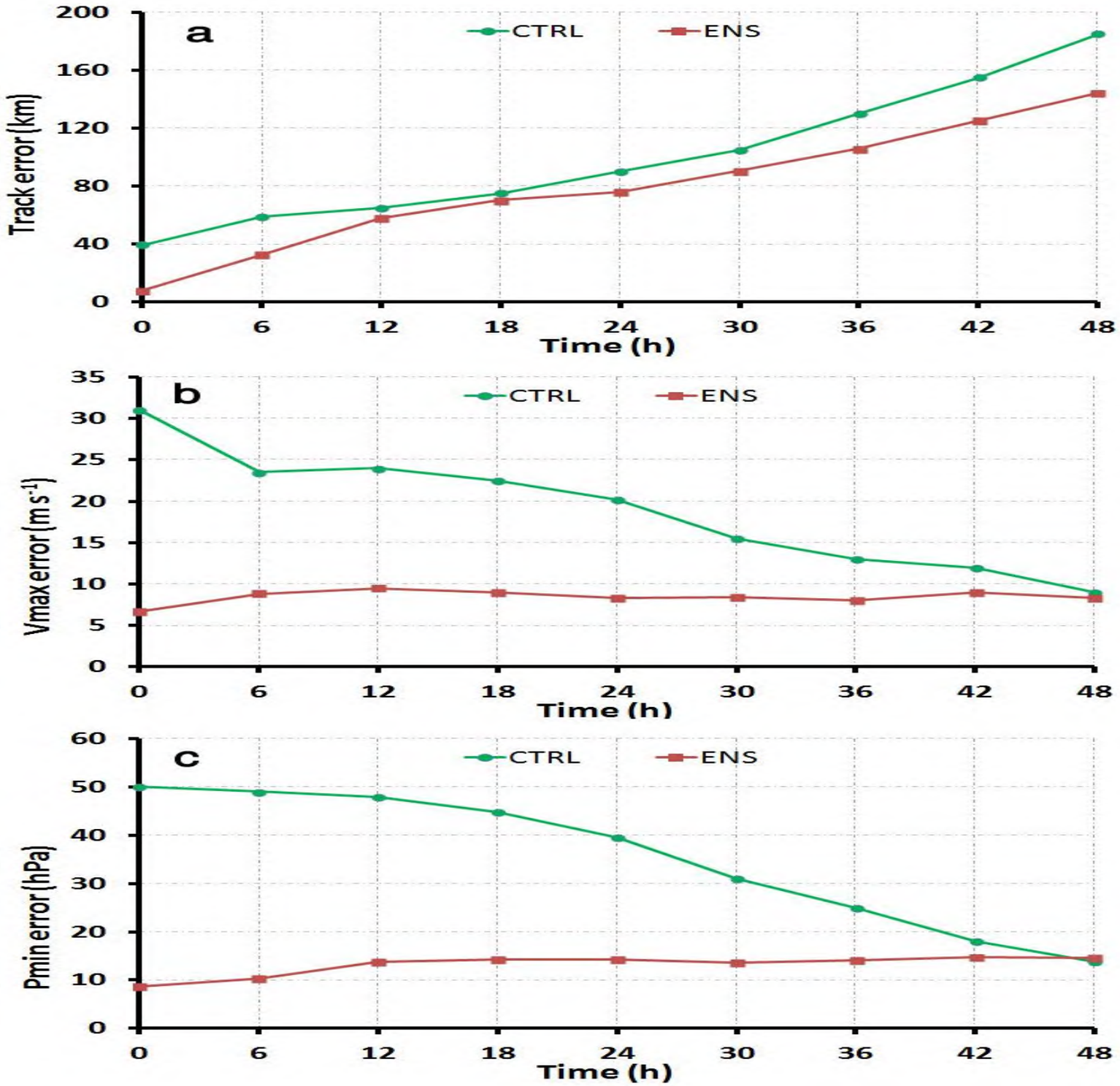


Figure 14. Mean absolute errors from the WRF-GD, Eta-GD and Eta-GD ensemble mean (red) and CTRL run (blue) for all four typhoons at different forecast hours for (a) track (km), (b) maximum wind speed (m s^{-1}), and (c) minimum SLP (hPa).

A few thoughts

Are the storm scale circulations associated with tropical cyclones and the large-scale environment in quasi-equilibrium at the model initial conditions based on global analyses? NO.

How long does it take for the TC structure (including size) and intensity to adjust (the adjustment time scale) to the storm environment in high resolution models? ~1-2 days depending on the storm intensity

Is the adjustment time scale much smaller than the time scale of the large-scale changes? NO!

- **Implication: It is important for the initial mesocale storm circulations to be well adjusted to the environment it is embedded in some way, otherwise the initial 24-36 h forecasts will be containminated by the adjustment process.**

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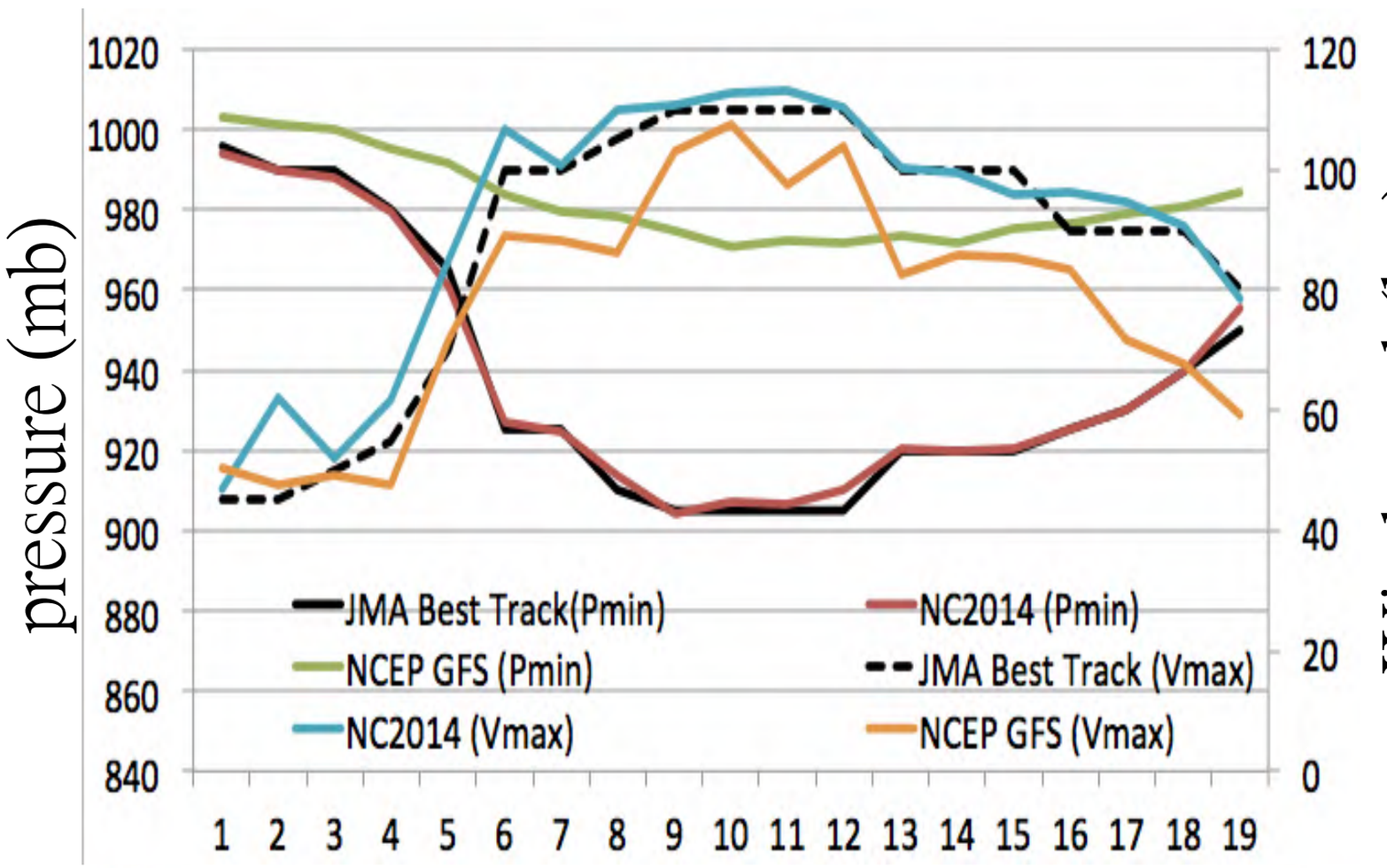
- Is the updated NC2014 scheme capable of reproducing the track, intensity and structure throughout the entire life cycle of a super tropical cyclone?
- How well does the scheme perform in realtime experimental forecast for relatively weak storms in Hawaii?
- The second goal of this study is to exam the updated NC2014 scheme in realtime and hindcast modes to evaluate the performance of the scheme.

Realtime & Hindcast Setup

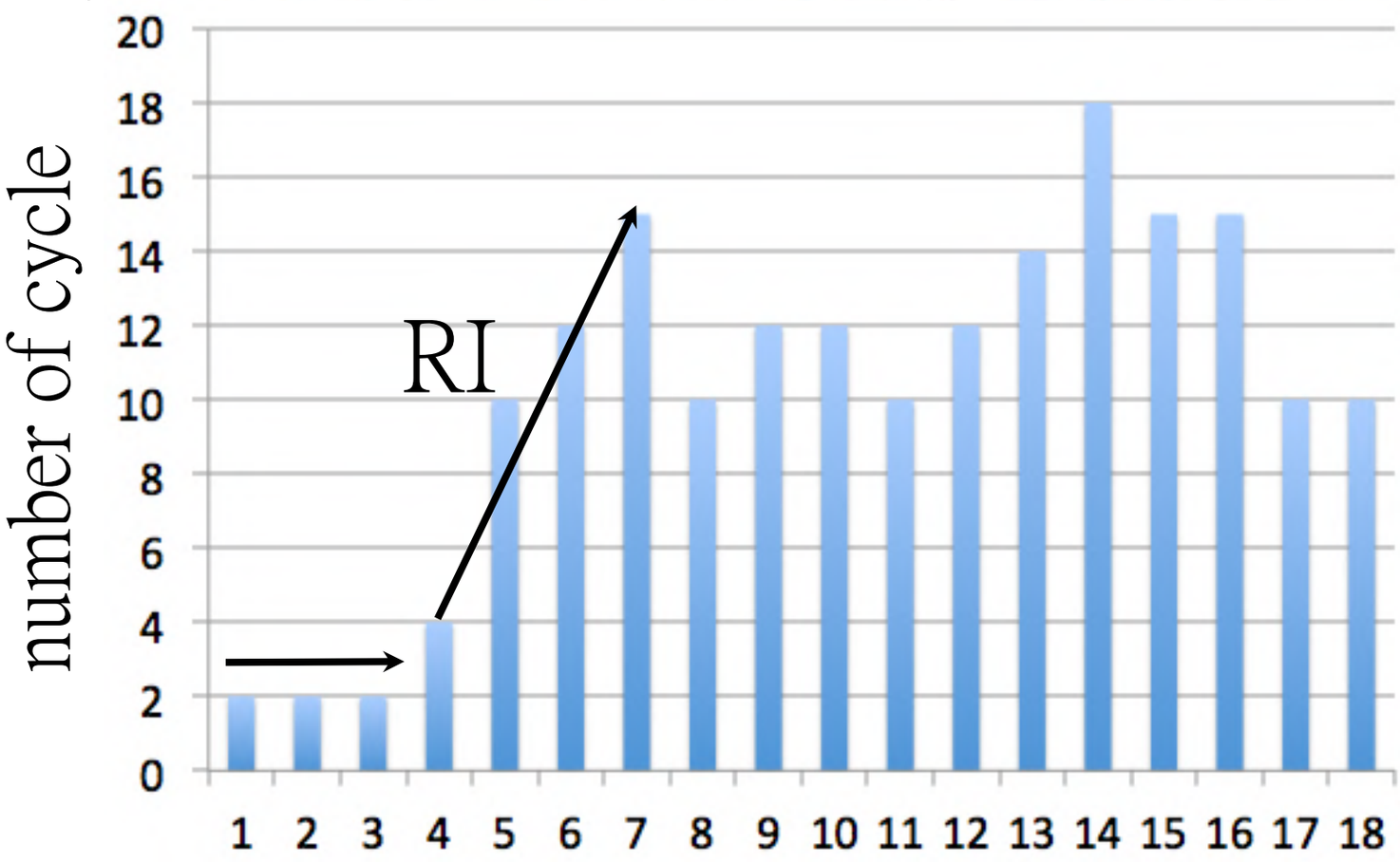
- Model: WRF V.3.5 with moving nest + NC2014 TC scheme
- Grid: 301x221x38(18km), 385x337x38(6km), 400x400x38 (2km,extra)
- ICs & LBCs: NCEP GFS 0.5 deg fcst
- Physics: WSM6(mp), RRTM(lw), Dudhia(sw), YSU(pbl), Grell(cu)
- Both d01 & d02 with cumulus parameterization
- Fcst length: 72hr every 12hr initialize
- Best Track Data : JMA (Jelawat - 2012), JTWC (Ana -2014)

High Resolution Hindcast with NC2014 Initialization for Super Typhoon Jelawat (2012)

Initial Conditions

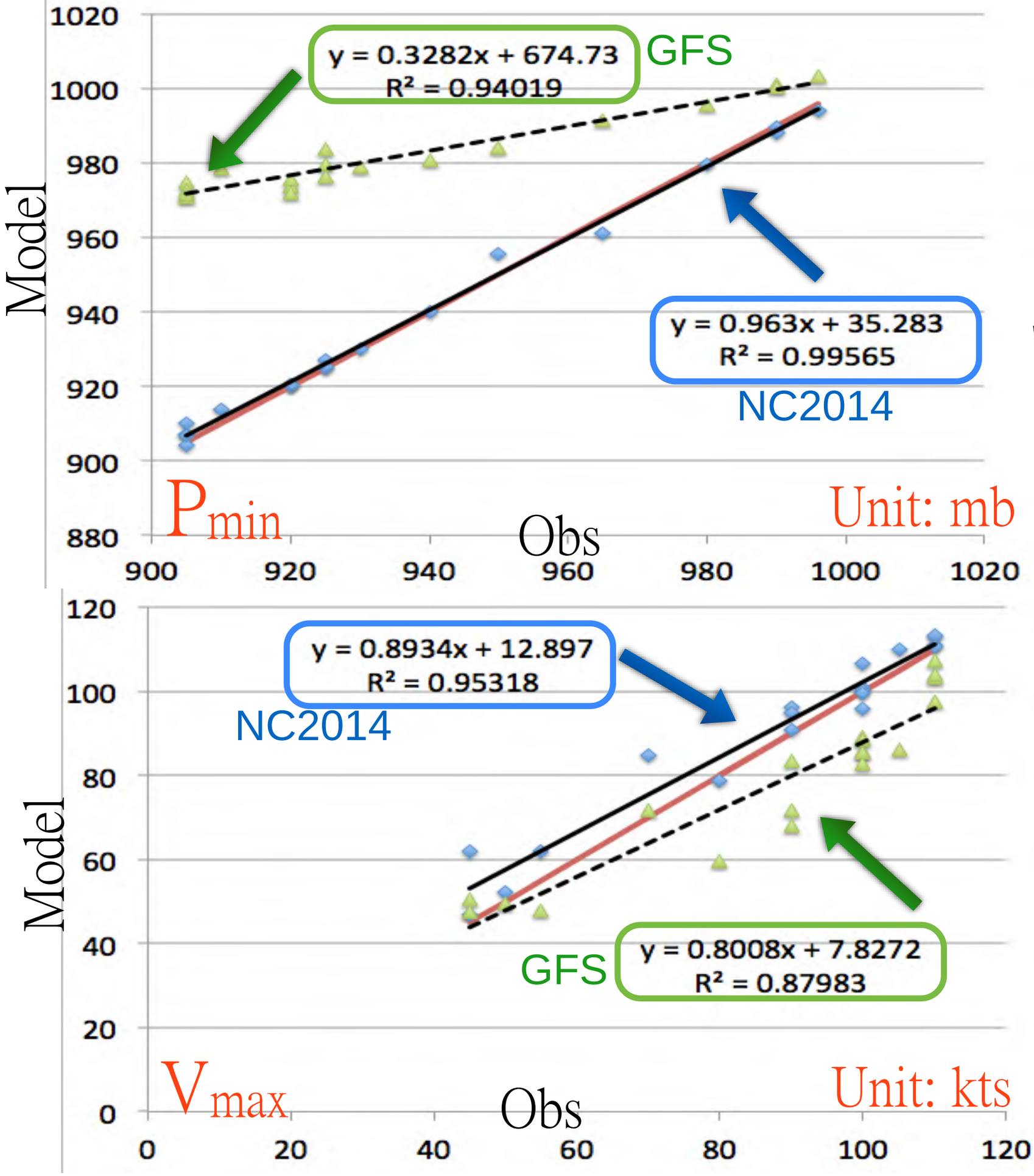


Spin-up Intensity



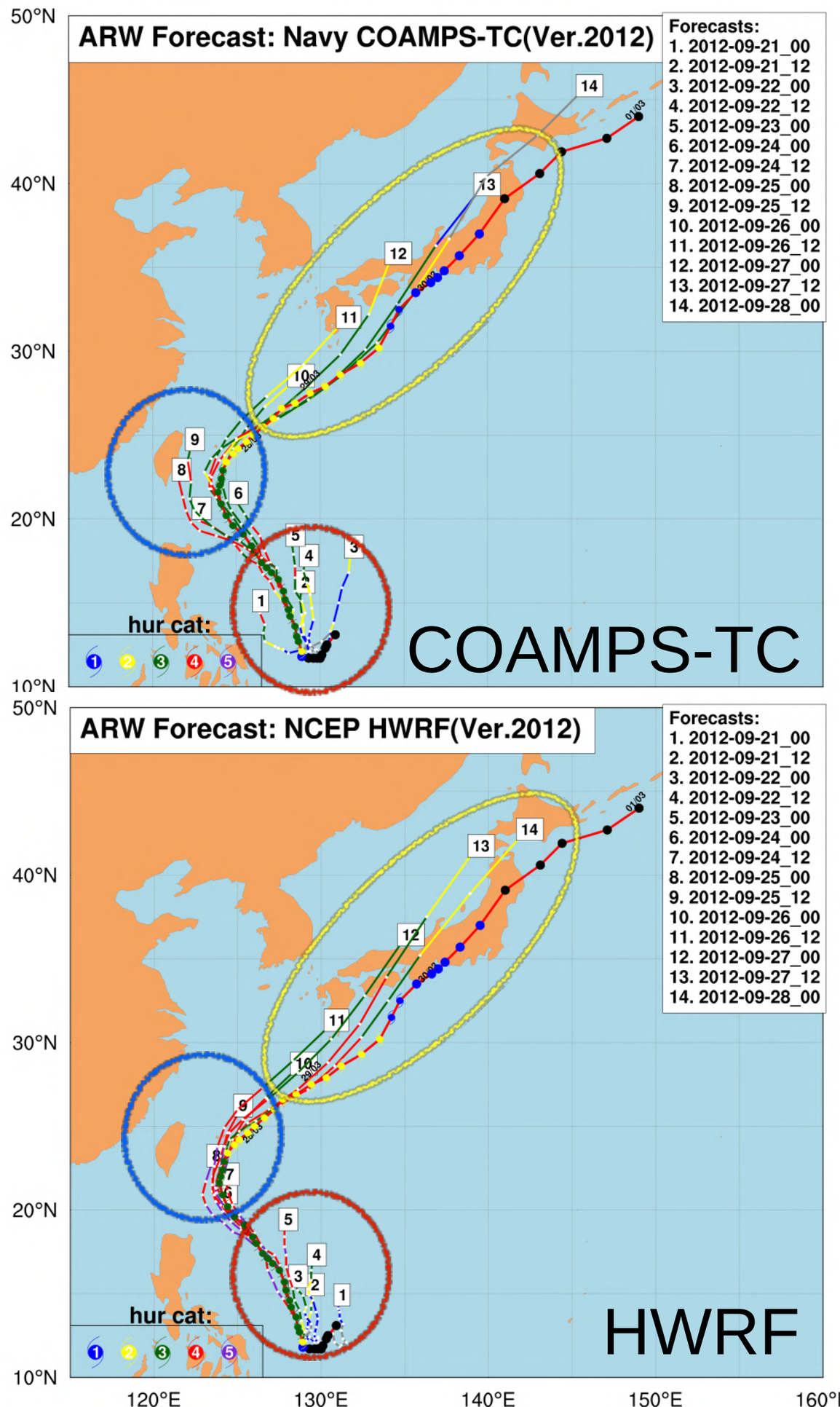
- NCEP GFS initial P_{min} is too high. But V_{max} is consistent with best track.
- The NC2014 scheme does not only match P_{min} but is also consistent with V_{max} very well.
- For a strong TC, the NC2014 scheme needs more spin-up cycles than weak storm (> 10)

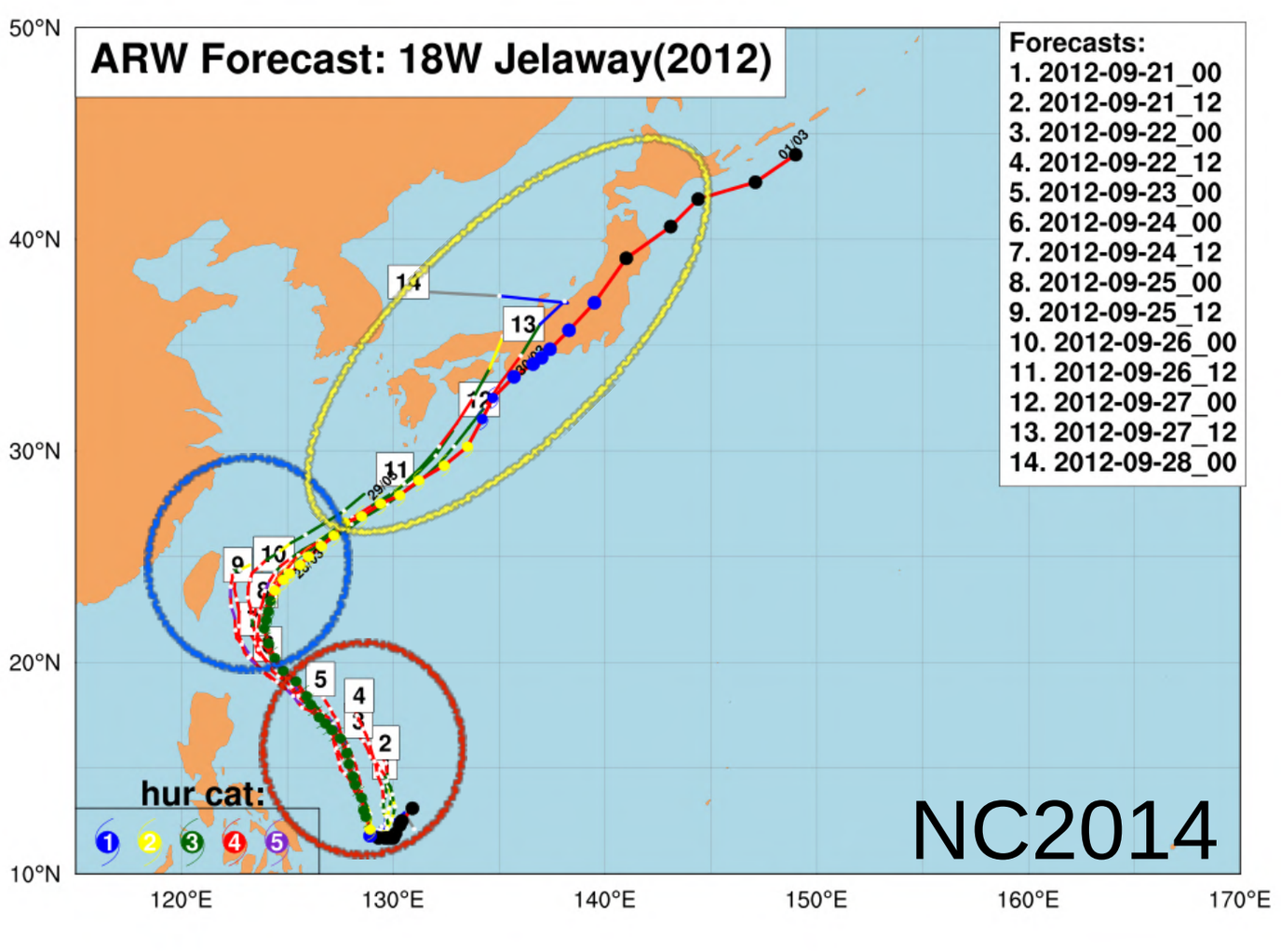
Linear Regression of Spin-up Intensity



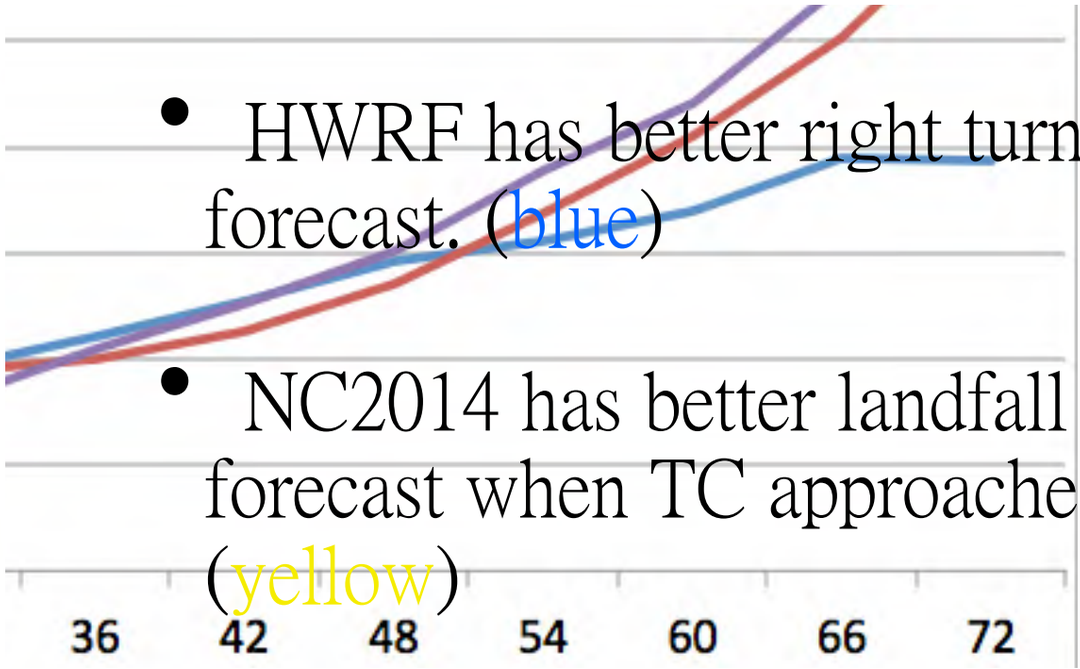
- The NC2014 scheme produces better intensity at the initial time.
- The NC2014 scheme corrects the initial weak TC intensity error.

Hindcast Results





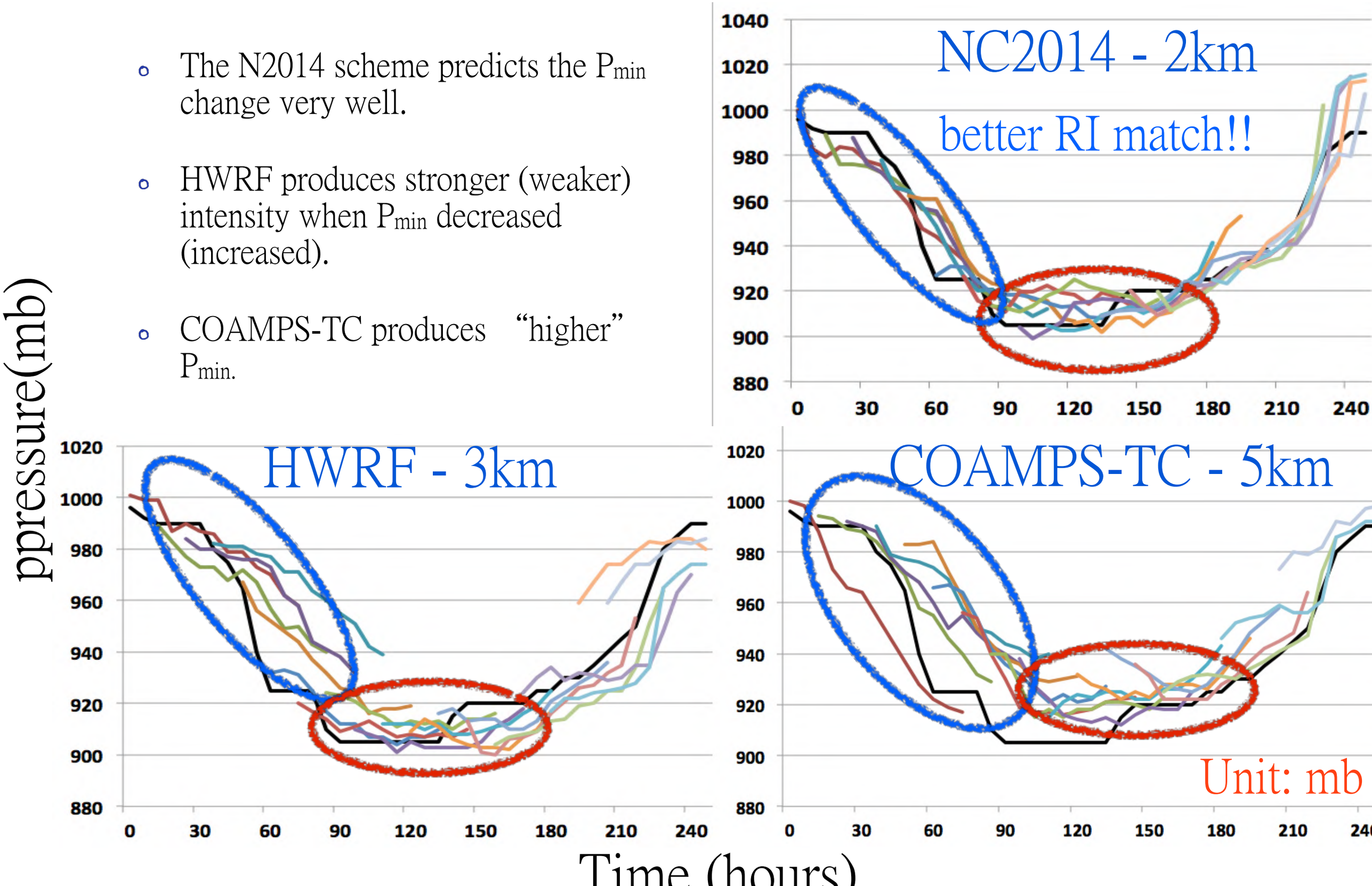
- N2014 has small initial track spread. (red)



- HWRF has better right turn track forecast. (blue)
- NC2014 has better landfall track forecast when TC approaches Japan. (yellow)

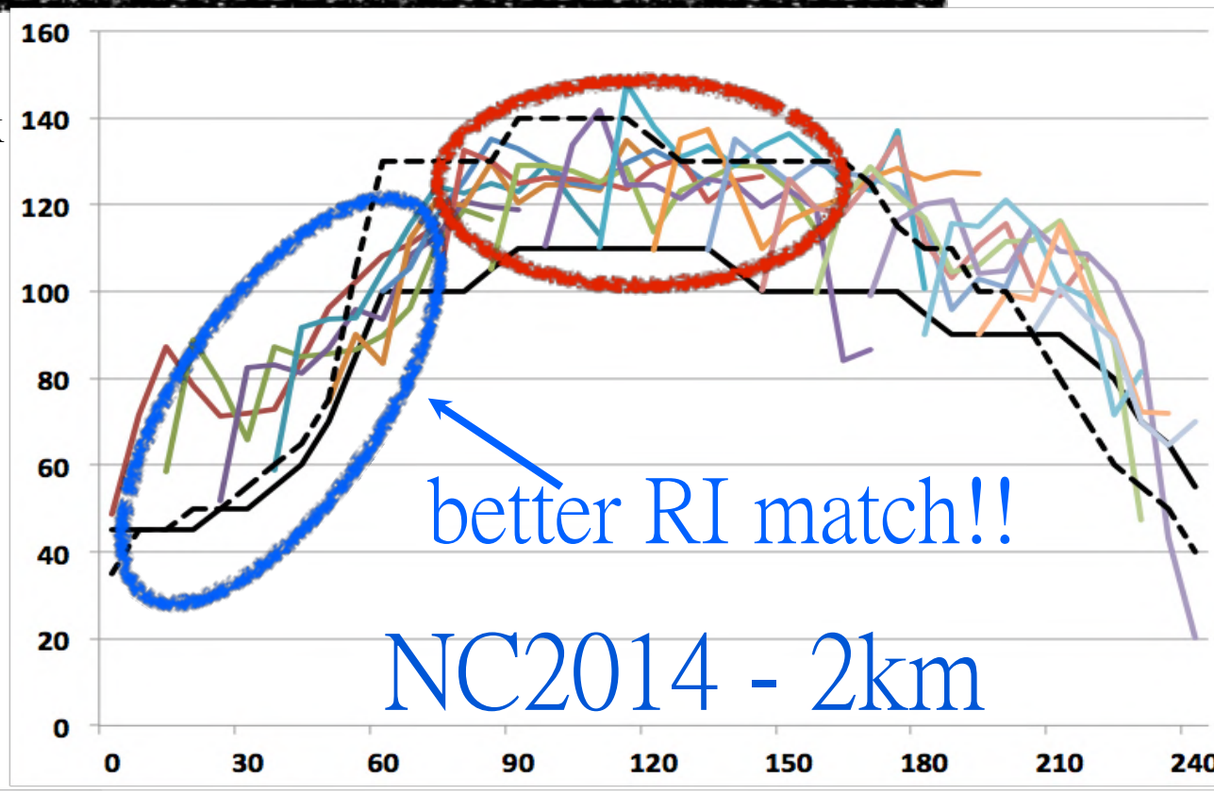
P_{min} Forecast

- The N2014 scheme predicts the P_{min} change very well.
- HWRF produces stronger (weaker) intensity when P_{min} decreased (increased).
- COAMPS-TC produces "higher" P_{min}.

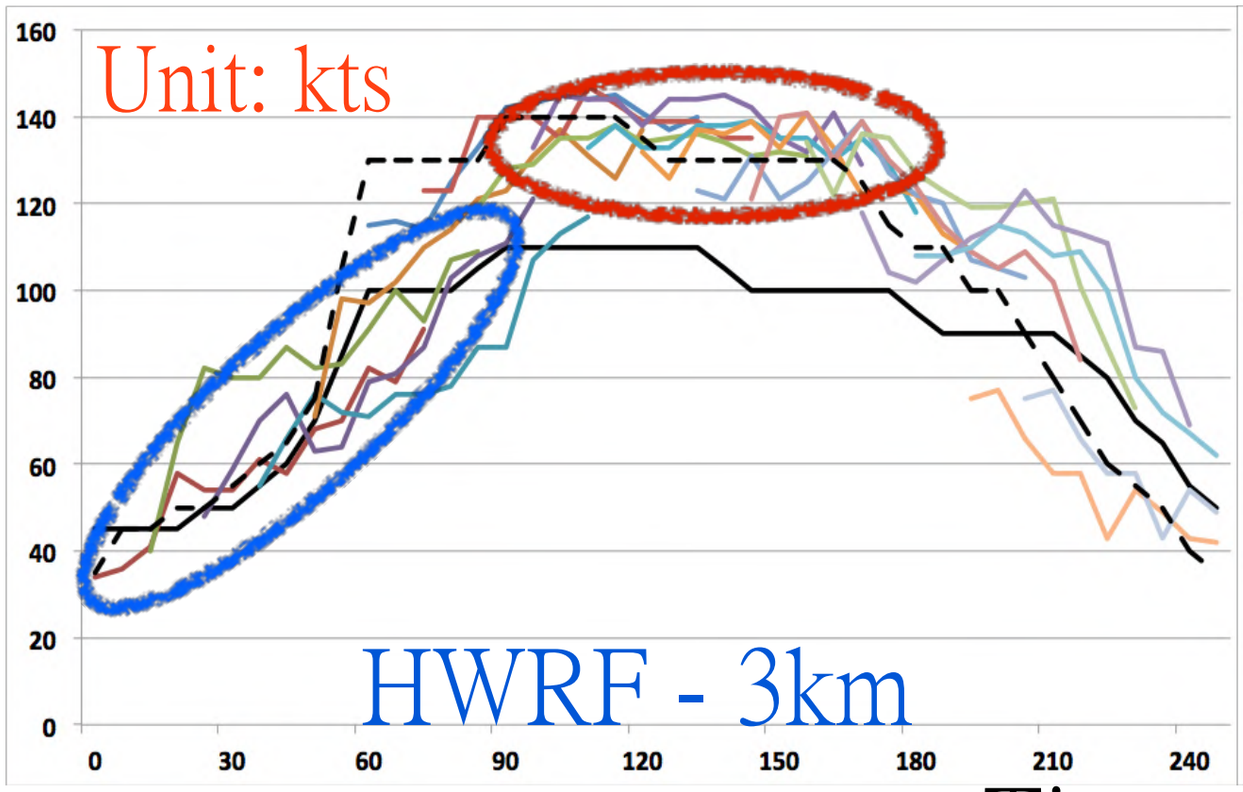


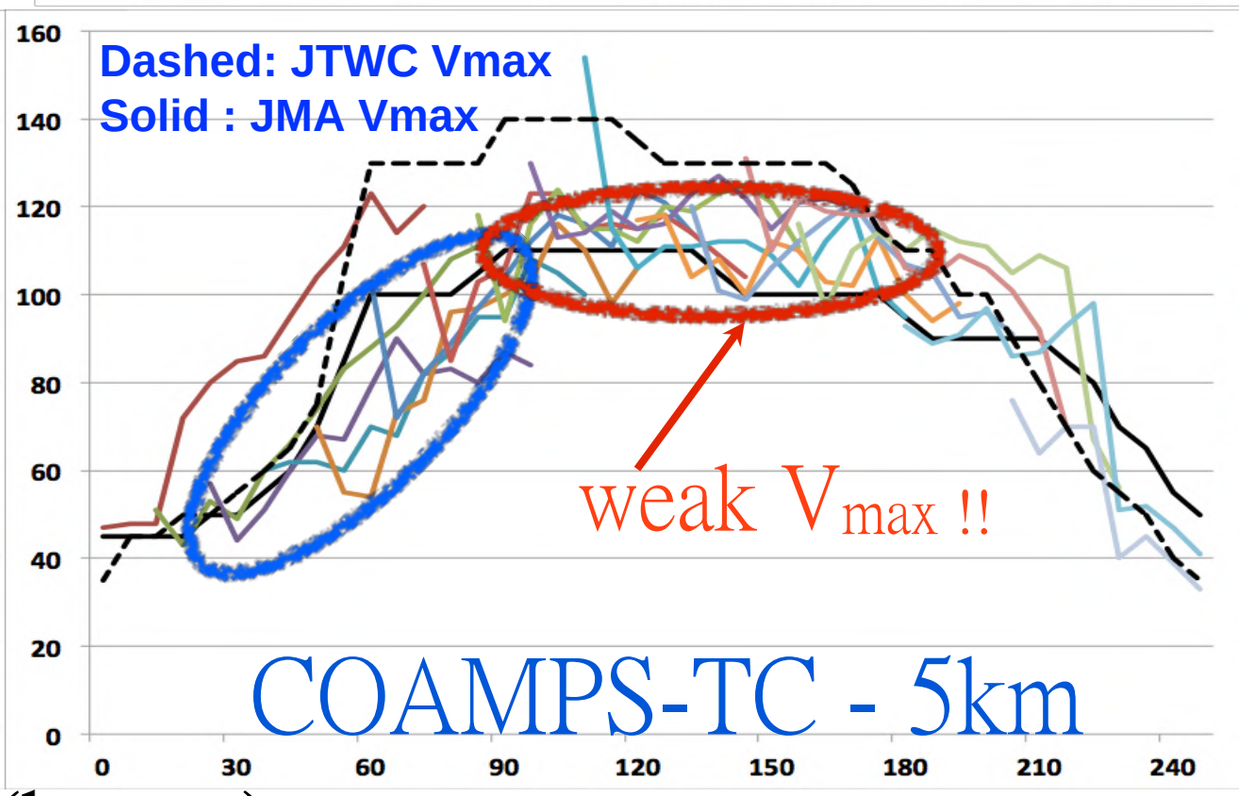
V_{max} Forecast

- The N2014 scheme predicts the V_{max} change very well.
- HWRF produces V_{max} consist with JTWC’ s data
- COAMPS-TC produces “lower” V_{max}



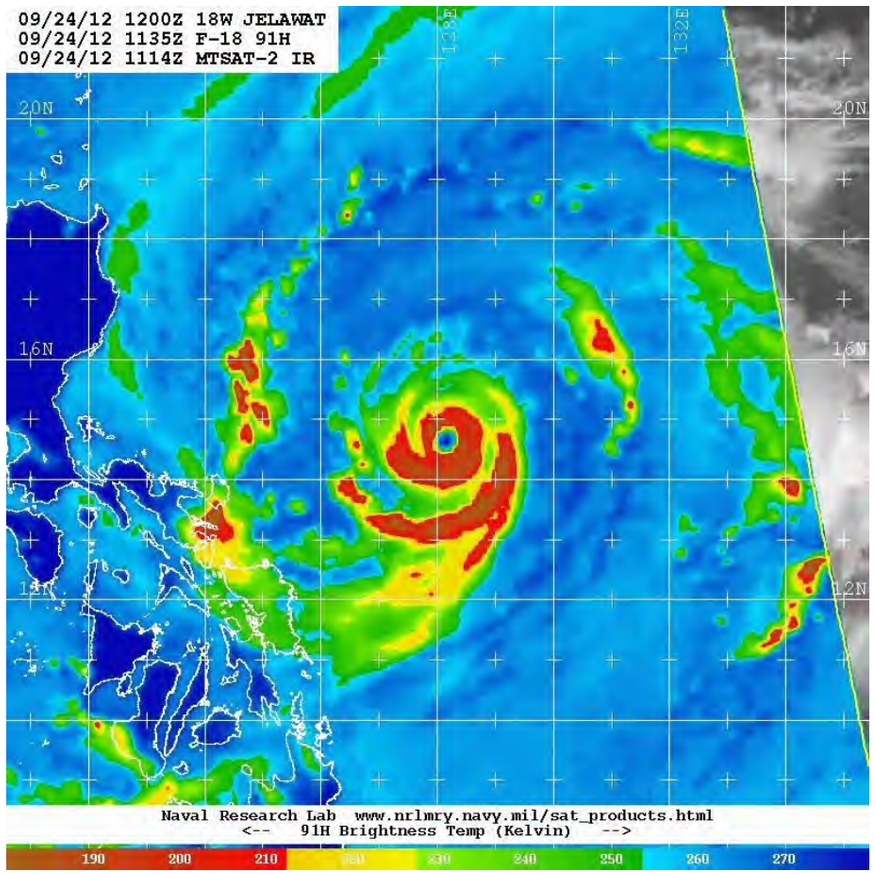
windspeed(kts)



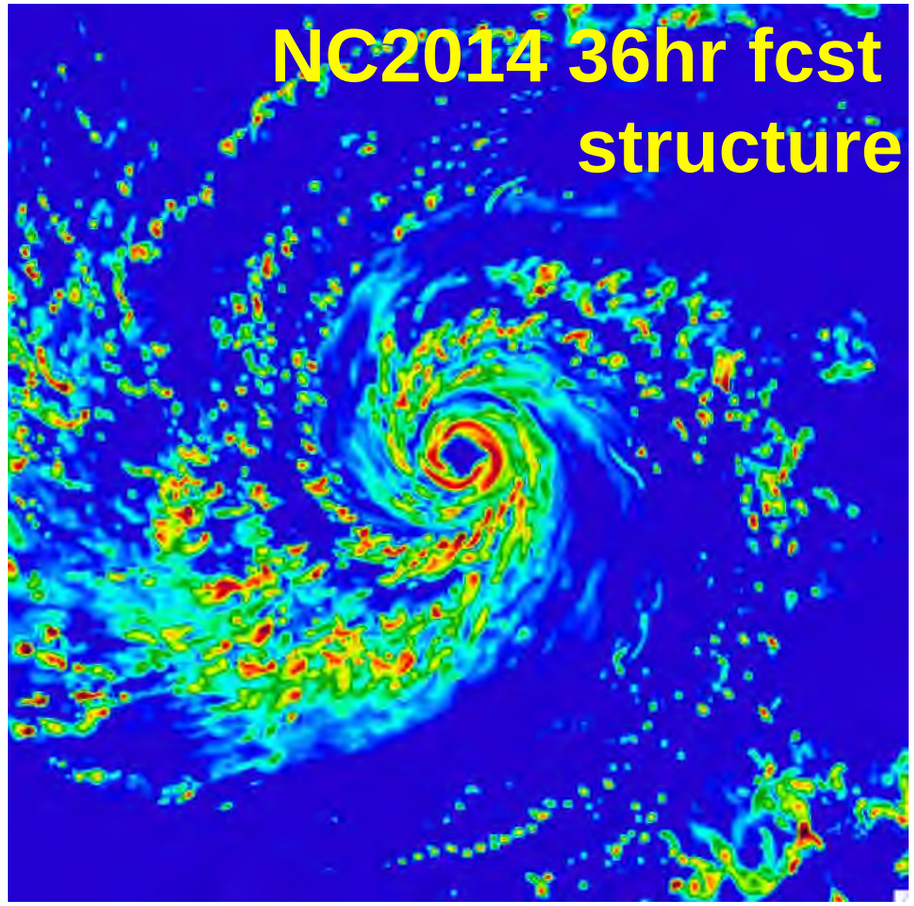


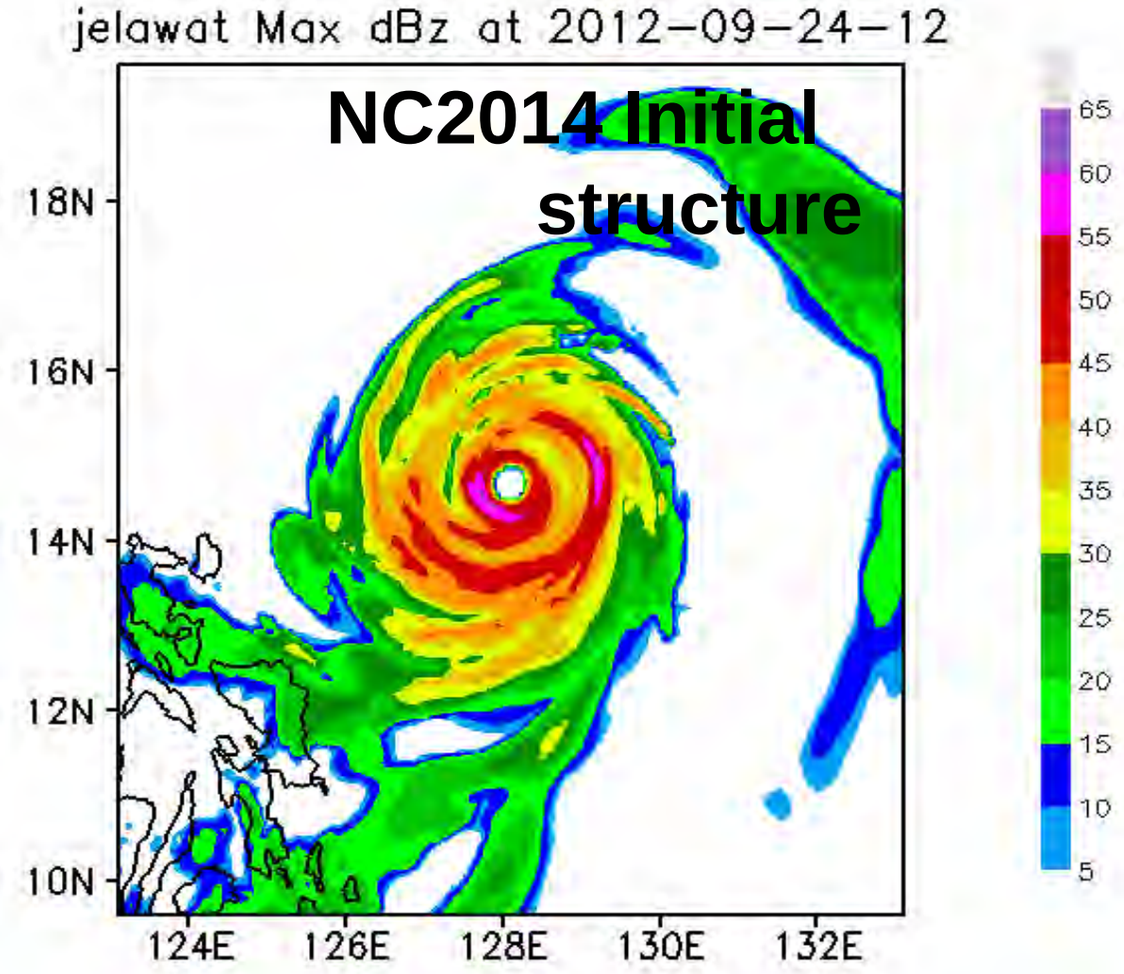
Time (hours)

Typhoon Structure



- The 36hr hindcast TC structure is similar to micro-wave satellite image. (upper right)
- The NC2014 scheme produces similar TC structure at T=0 (lower-right)





Summary 1

- The NC2014 scheme successfully reproduces TC track forecast and the intensity change of Typhoon Jelawat (2012) with a 2km high resolution hindcast.

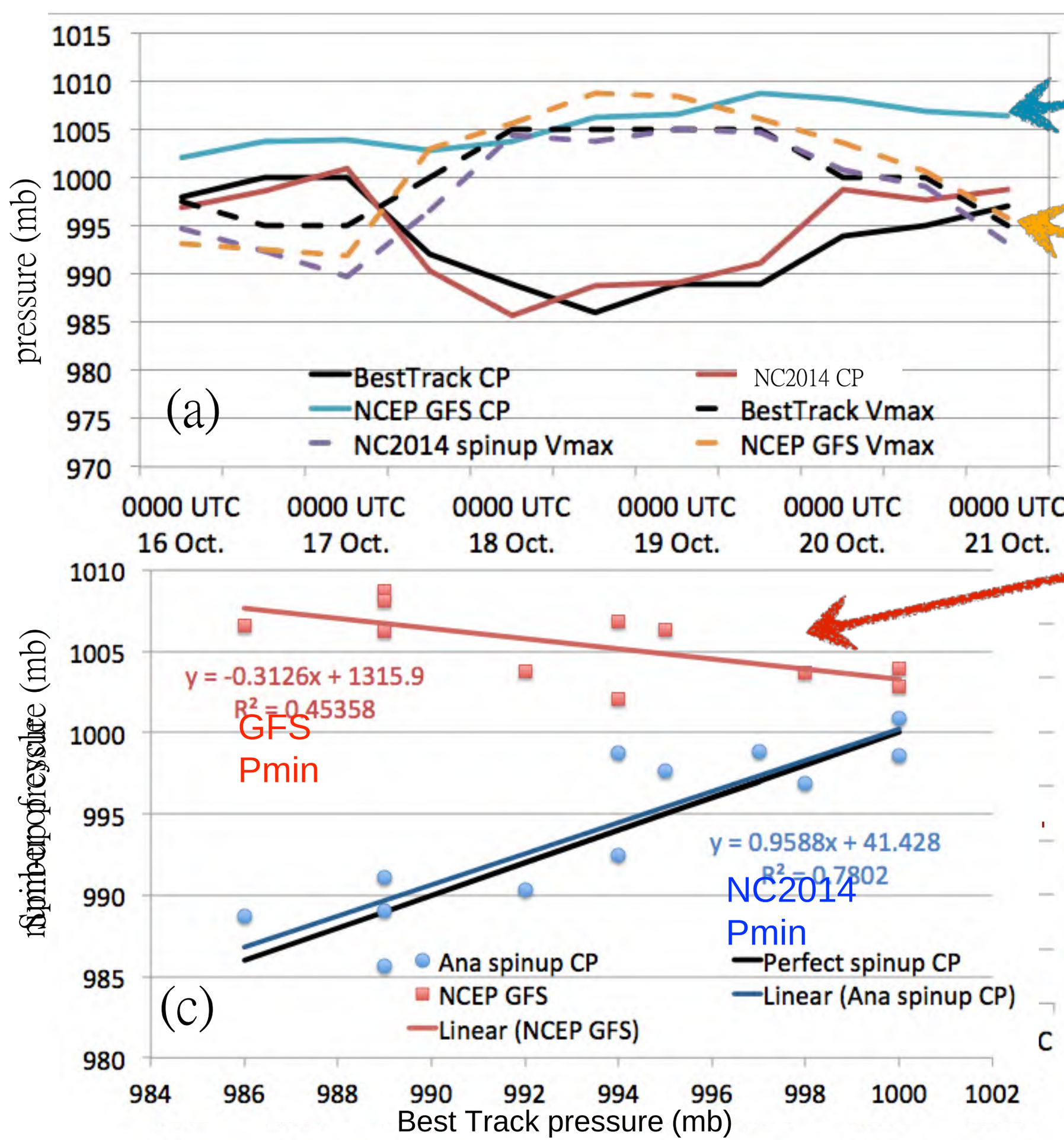
- The error statistic analysis shows that the scheme performs the intensity forecast reasonably well as compared with HWRF(2012), and COAMPS-TC(2012). Especially in predicting rapid intensification (RI) process.

- Inserting a warm core, the N2014 scheme reduces the number of cycles during the spin-up process than the original NC2011 scheme.

- The storm structure is predicted very well by the NC2014 scheme.

Hurricane Ana (2014) Realtime Forecast with NC2014 Tropical Cyclone Initialization Scheme

Initialization



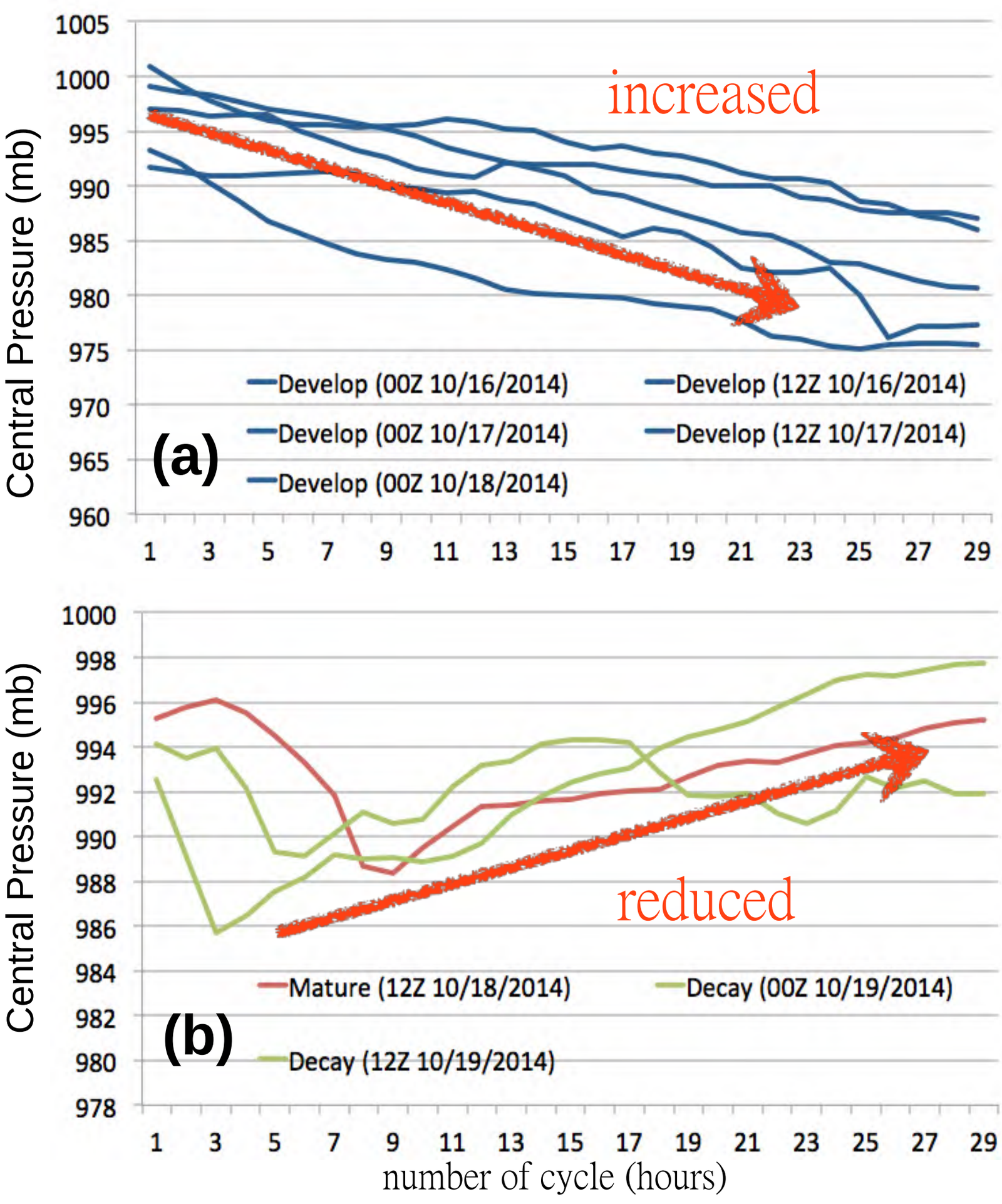
NCEP GFS P_{min} is too high!!

NCEP GFS has reasonable V_{max} !!

NCEP GFS P_{min} is too high and low correlation as model ICs!!

NC2014 generates Pmin and Vmax consistent with observations.

Linear Regression of Spin-up Intensity

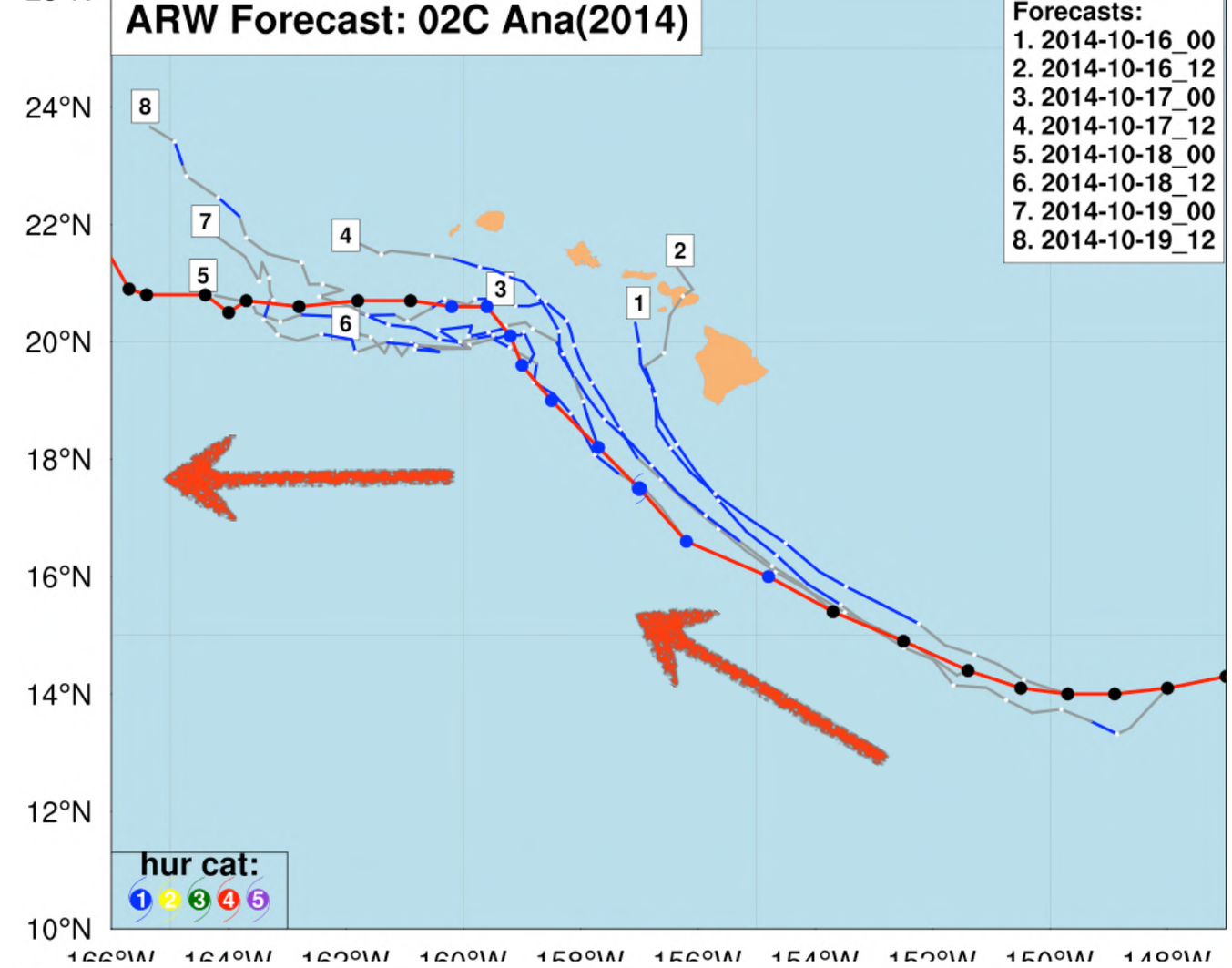


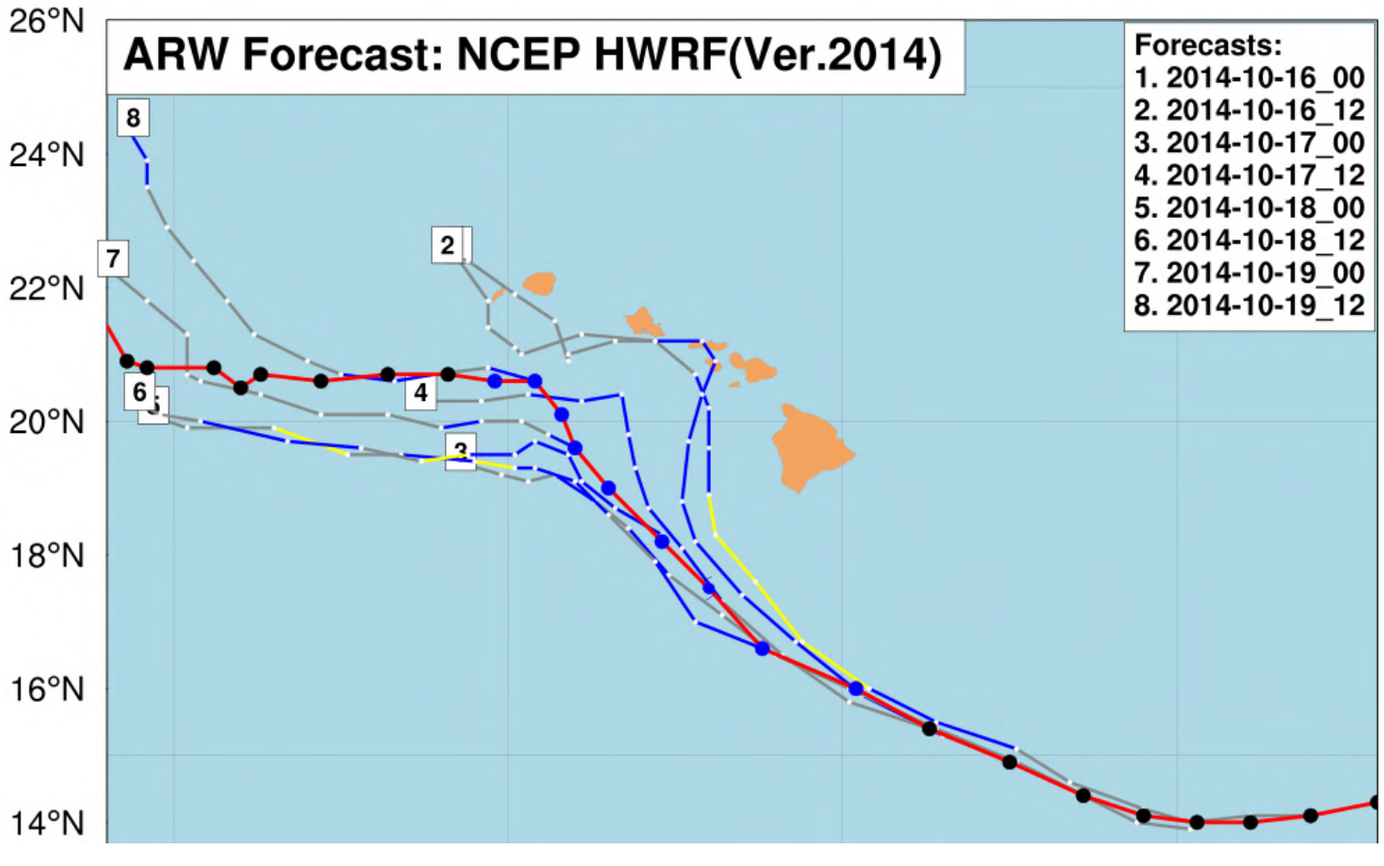
Different Stage of Hurricane Spin-up

- The TC initialization scheme can predict the trend in the TC intensity when TC continues to deepen during the cycling run.

- NC2014 provides a forecast guidance to know TC intensity change in the near future. Figure b shows Hurricane Ana(2014) weakening during the cycle run for TC spin-up after the mature stage.

Realtime Forecast

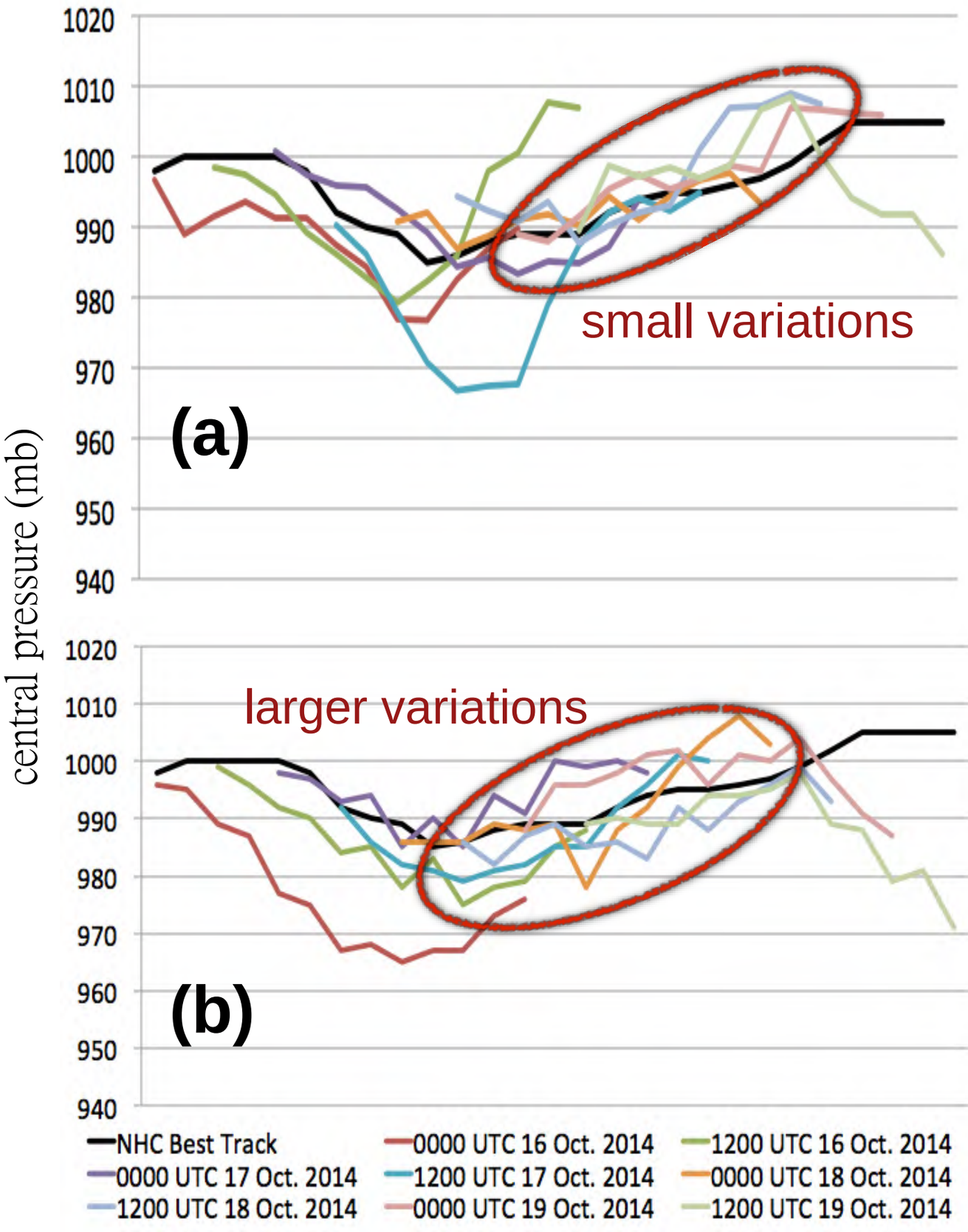




72hr Track Forecast

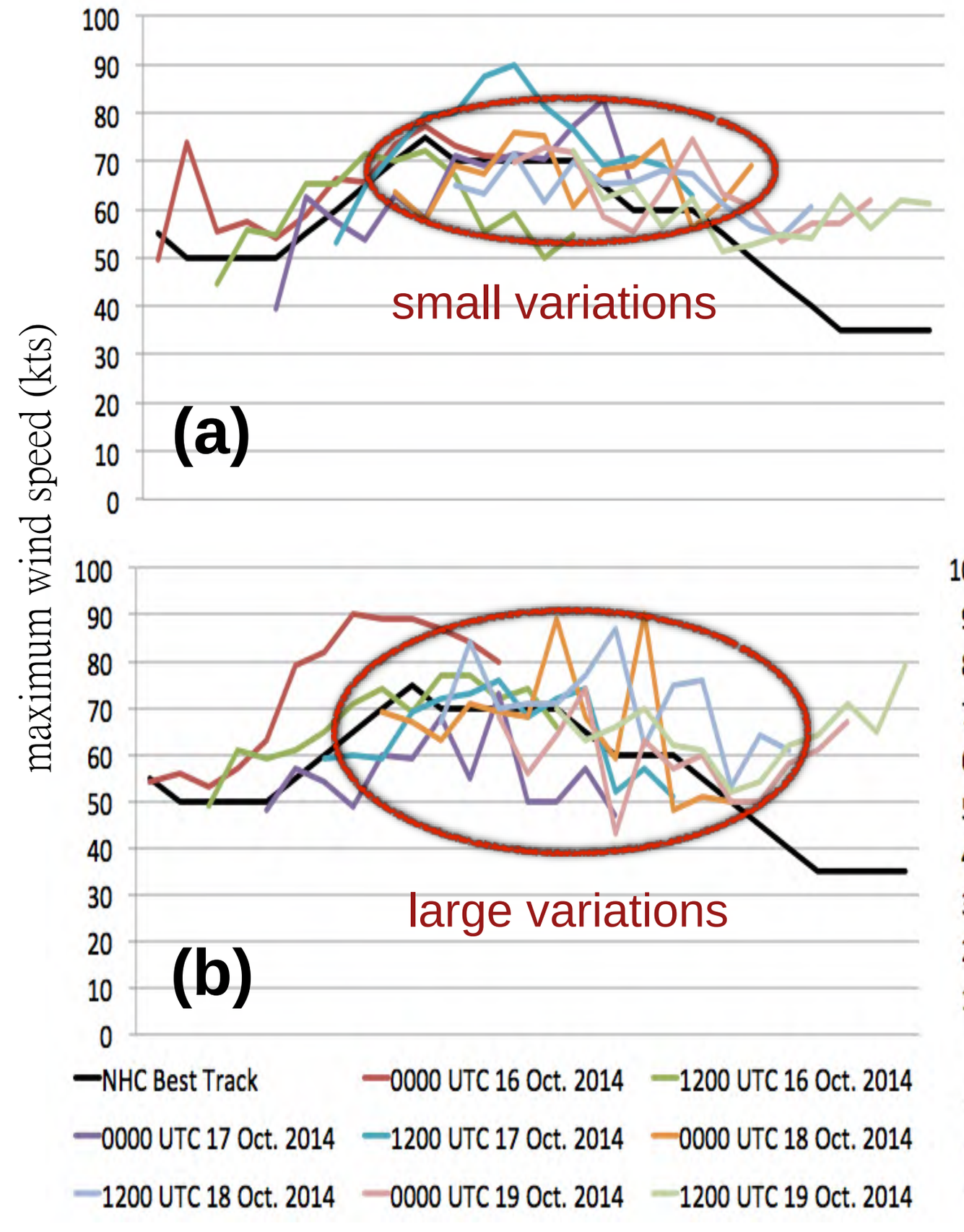
- The WRF with NC2014 scheme produces similar track forecast as best track, except run1 & 2.
- The NC2014 track forecast is better than HWRF and COAMPS-TC.

Central Pressure (mb) Forecast



- NC2014 produces too strong TC in run4. And HWRF produces much weaker TC.
- COAMPS "always" produces stronger TC as compared with observations.
- HWRF has larger variations in P_{min} than NC2014, but produces reasonably good intensity forecasts.

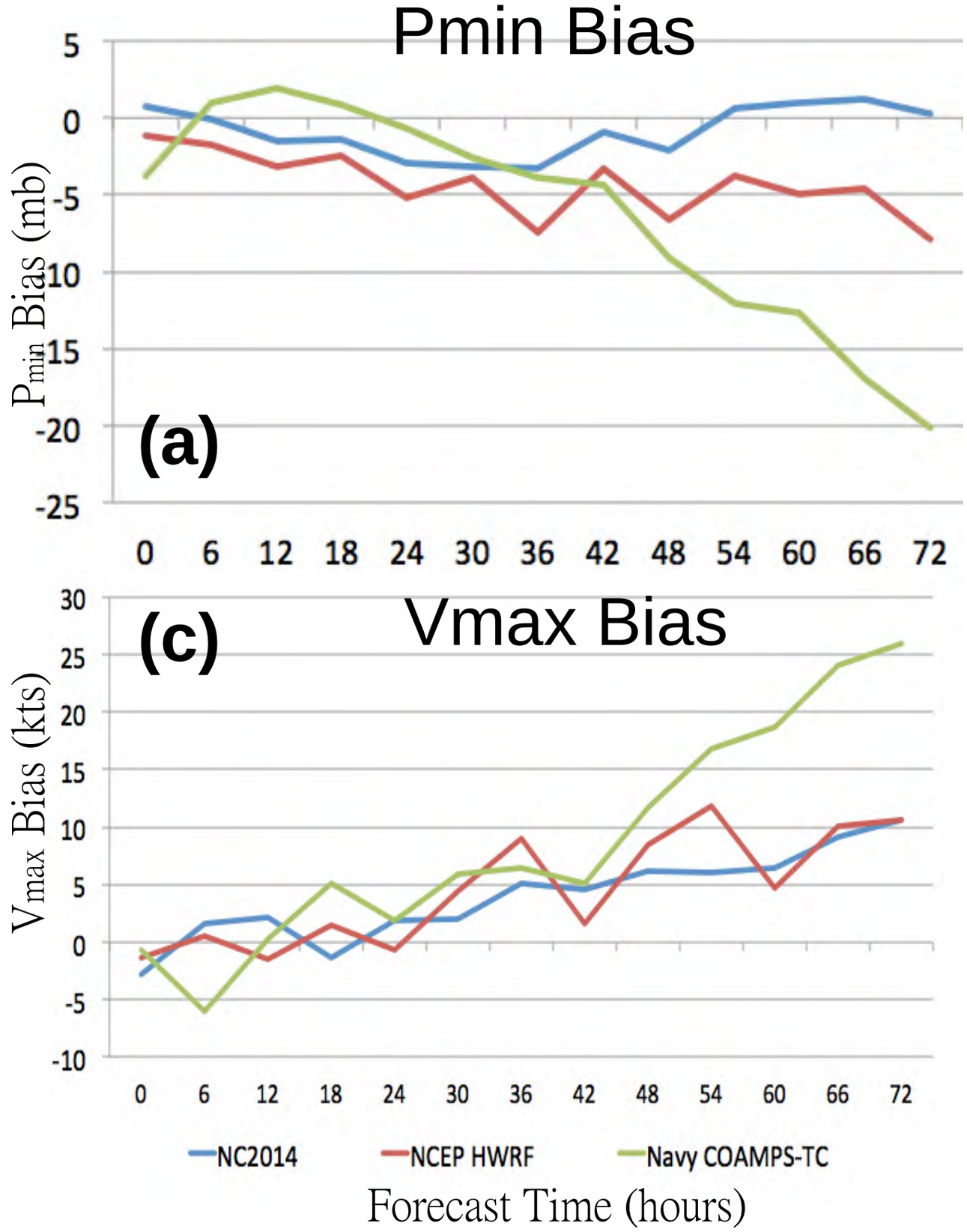
Maximum Wind (kts) Forecast

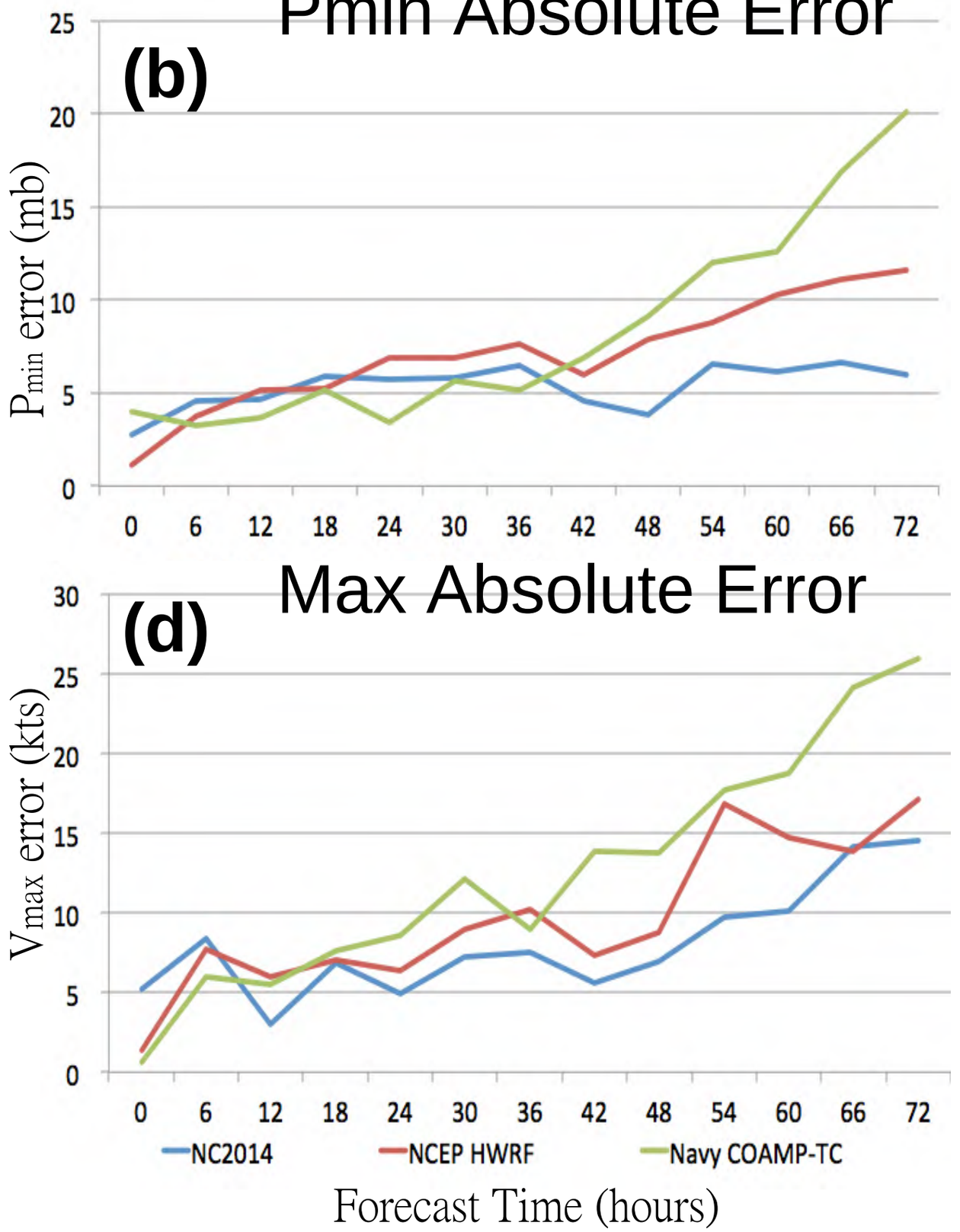


- Both NC2014 and HWRF capture the V_{max} well, but COMAPS produces too strong V_{max}
- Again, HWRF seems to have the imbalance features between the initial vortex and the environment during the forecast

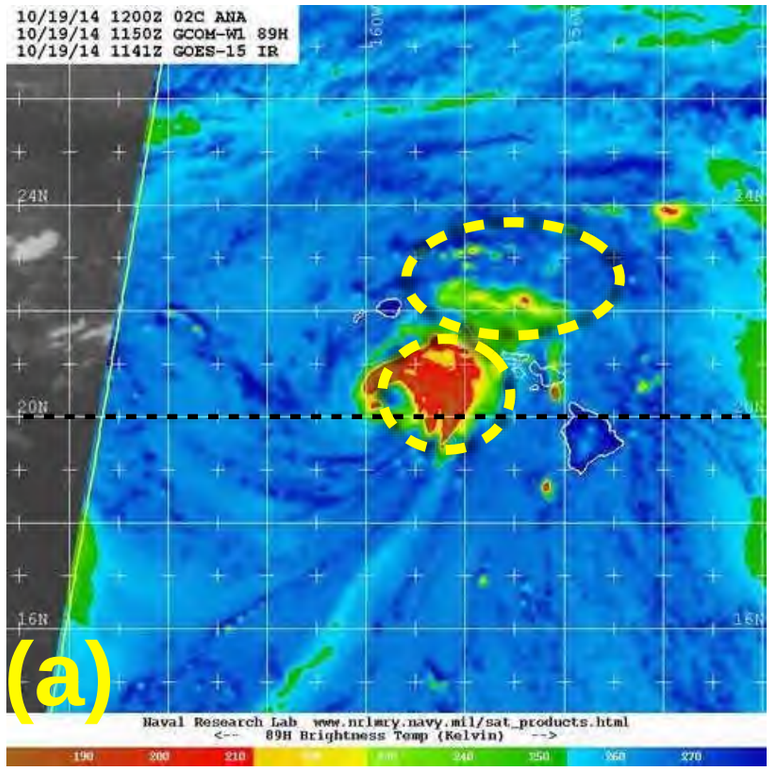
Intensity Verification

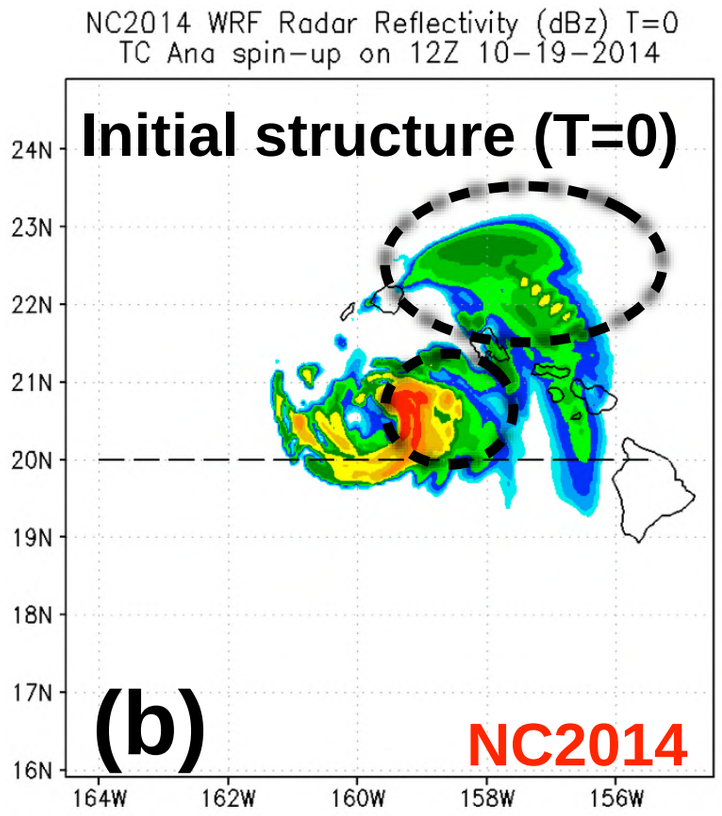
NC2014 produces smallest Intensity error in 72hr forecast !!

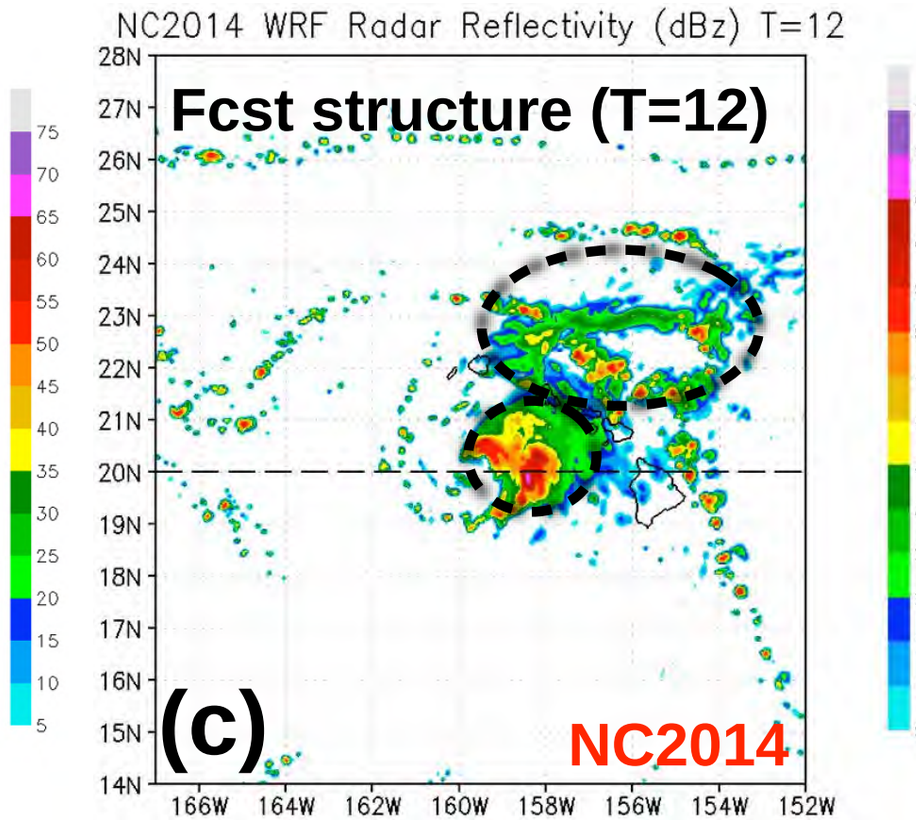


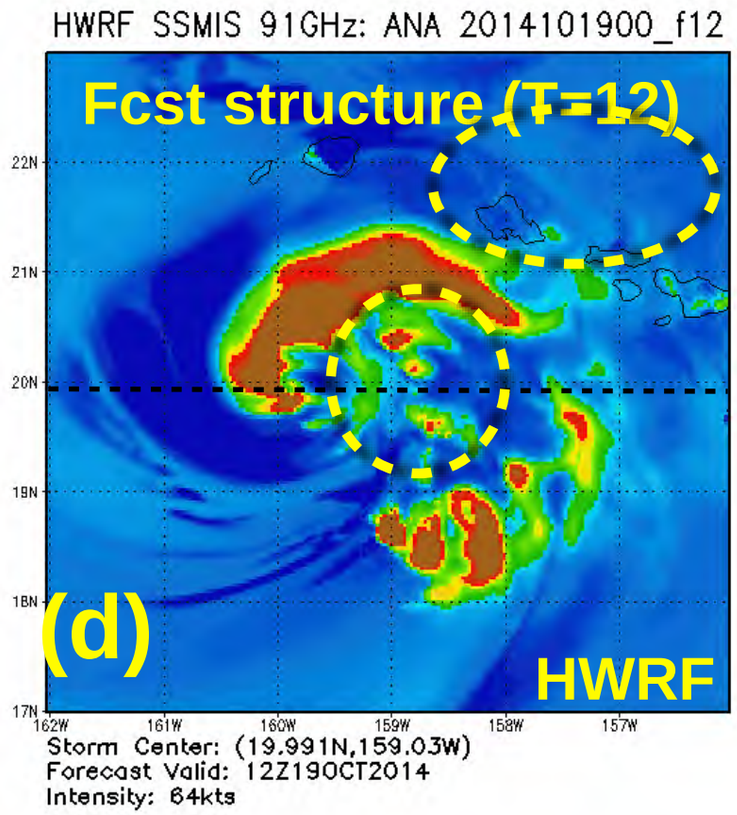


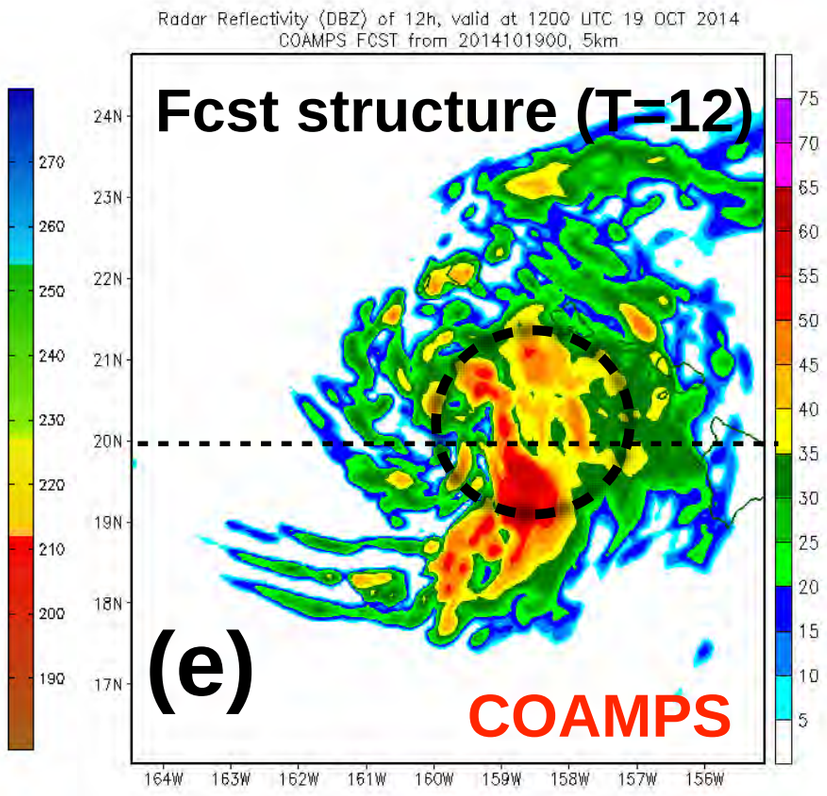
Hurricane Structure Comparison











- The NC2014 scheme produces similar TC structure as satellite observations at T=0.
- The 12hr forecast by NC2014 also produces the TC structure reasonably well as compared with HWRF and COAMPS-TC

Summary 2

- This is the first time that the NC2014 TC initialization method performed in experimental realtime TC forecast with TC Ana over the Hawaiian islands.

- The scheme produces good track, intensity and structure forecasts of Hurricane Ana from 0000Z 10/16/2014 to 1200 UTC 10/19/2014.

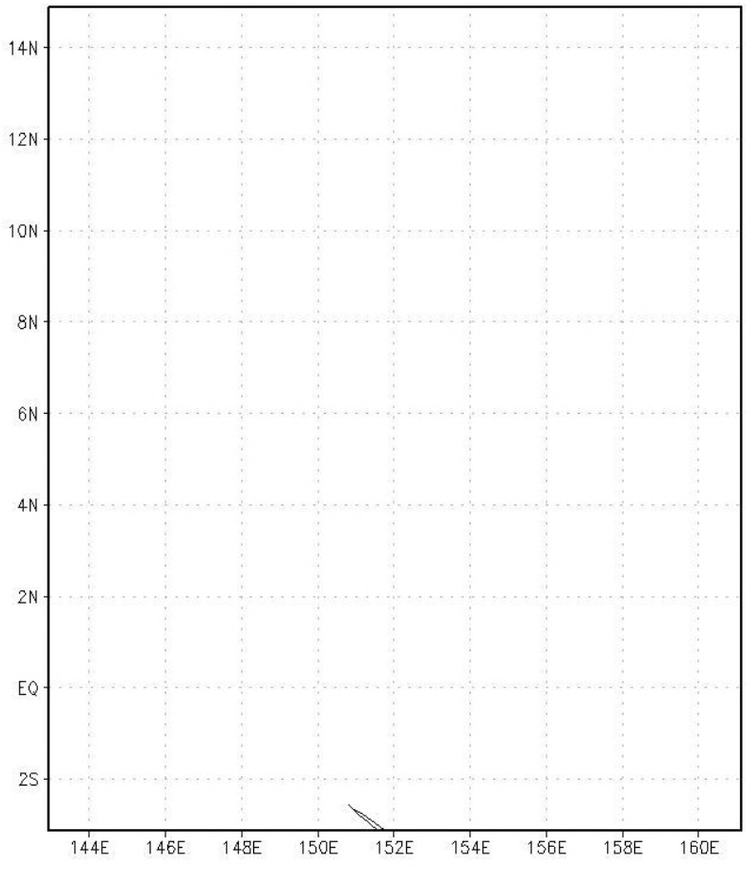
- The scheme has smallest intensity forecast error than HWRF, and COAMPS-TC.

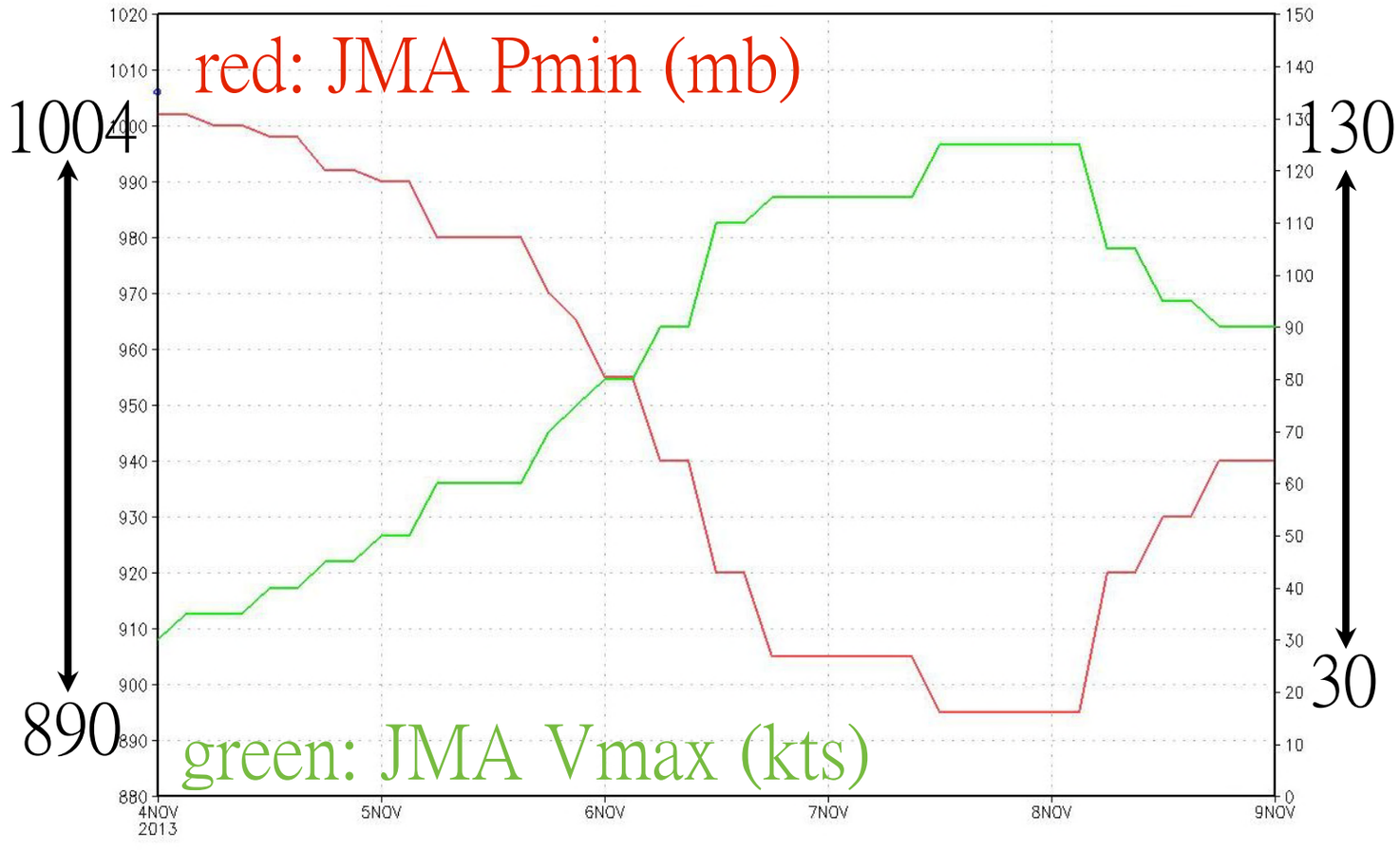
- The scheme could possibly provide a good guide for forecasting hurricane intensity change during the initial spin-up process.

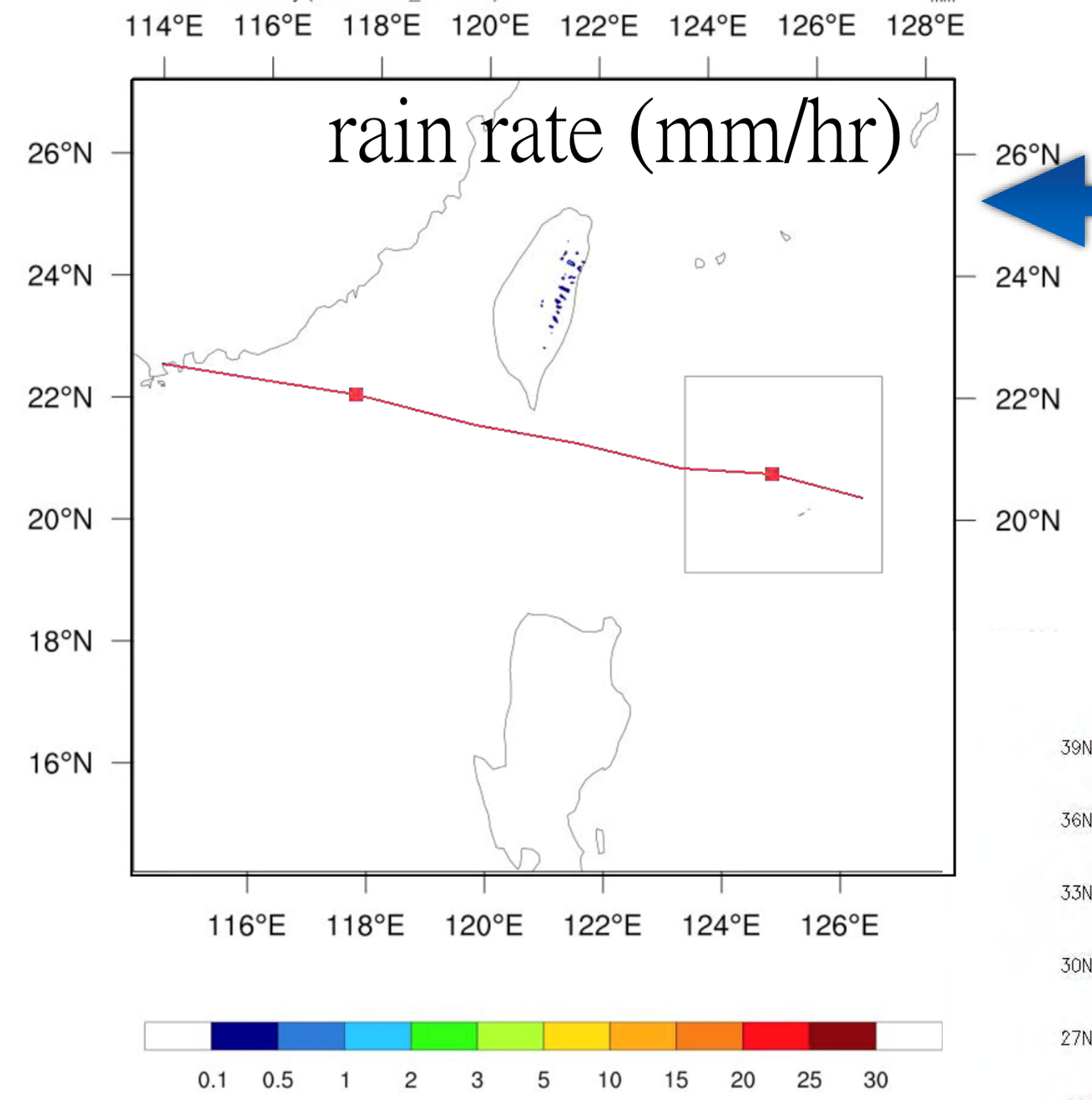
- Compared with observations, the NC2014 scheme generates a good TC structure and intensity at the model initial time. Thus, in addition to better track, intensity forecasts, this will also improve rainfall forecast.

Other Tropical Cyclone Applications

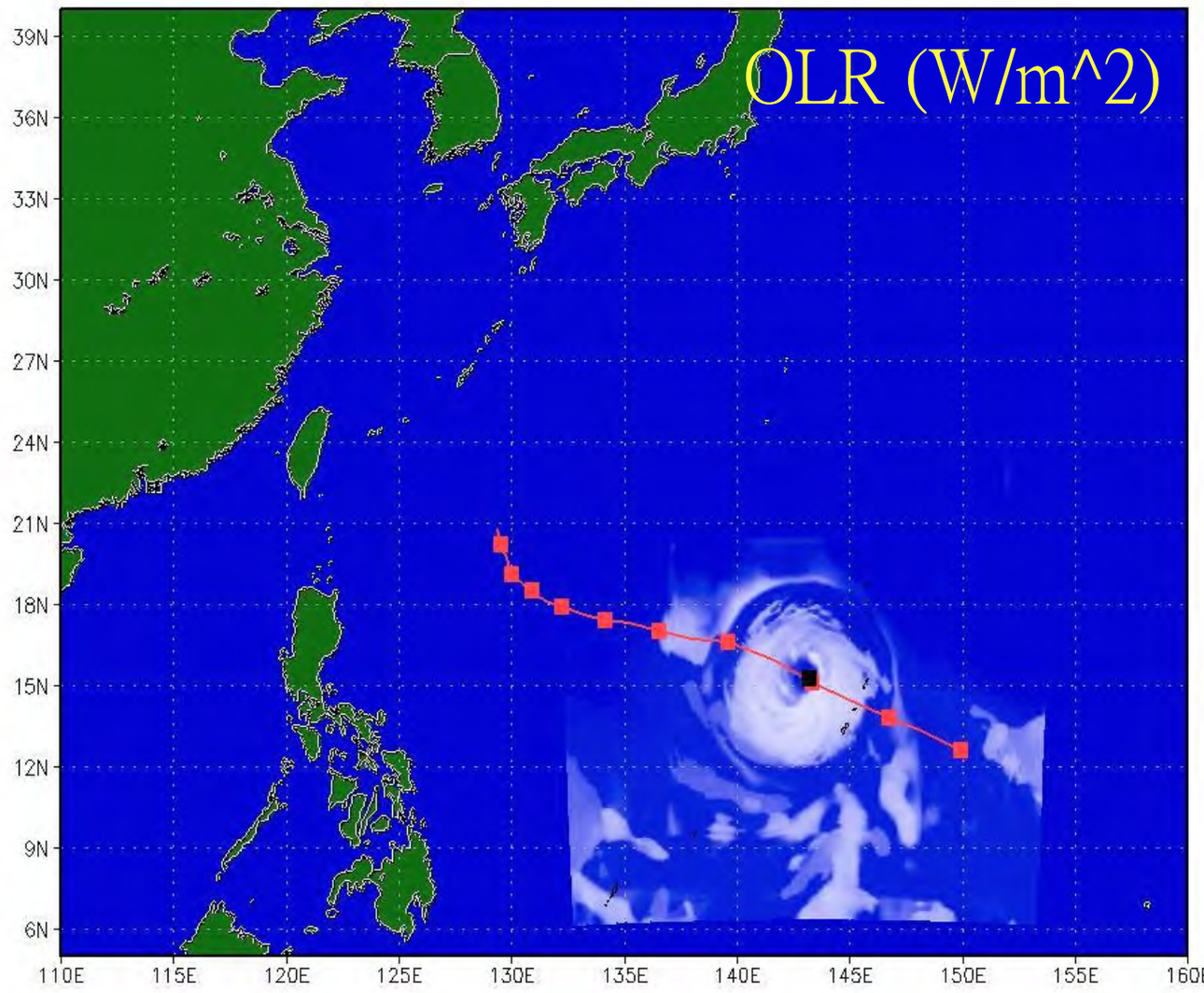
Super Typhoon (Cat.5) Haiyan
Model init: 0000 04 Nov. 2013
Fcst: 120 hr
Resolution: 18 - 6 - 2km



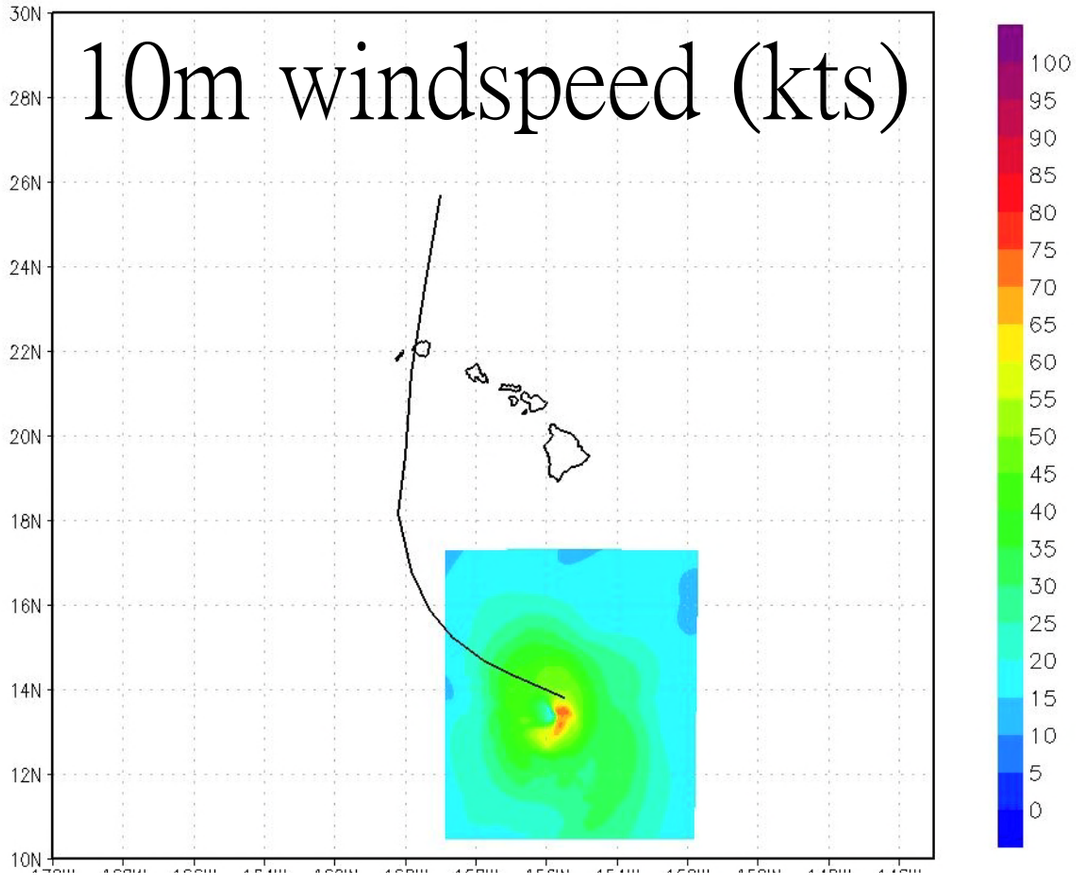


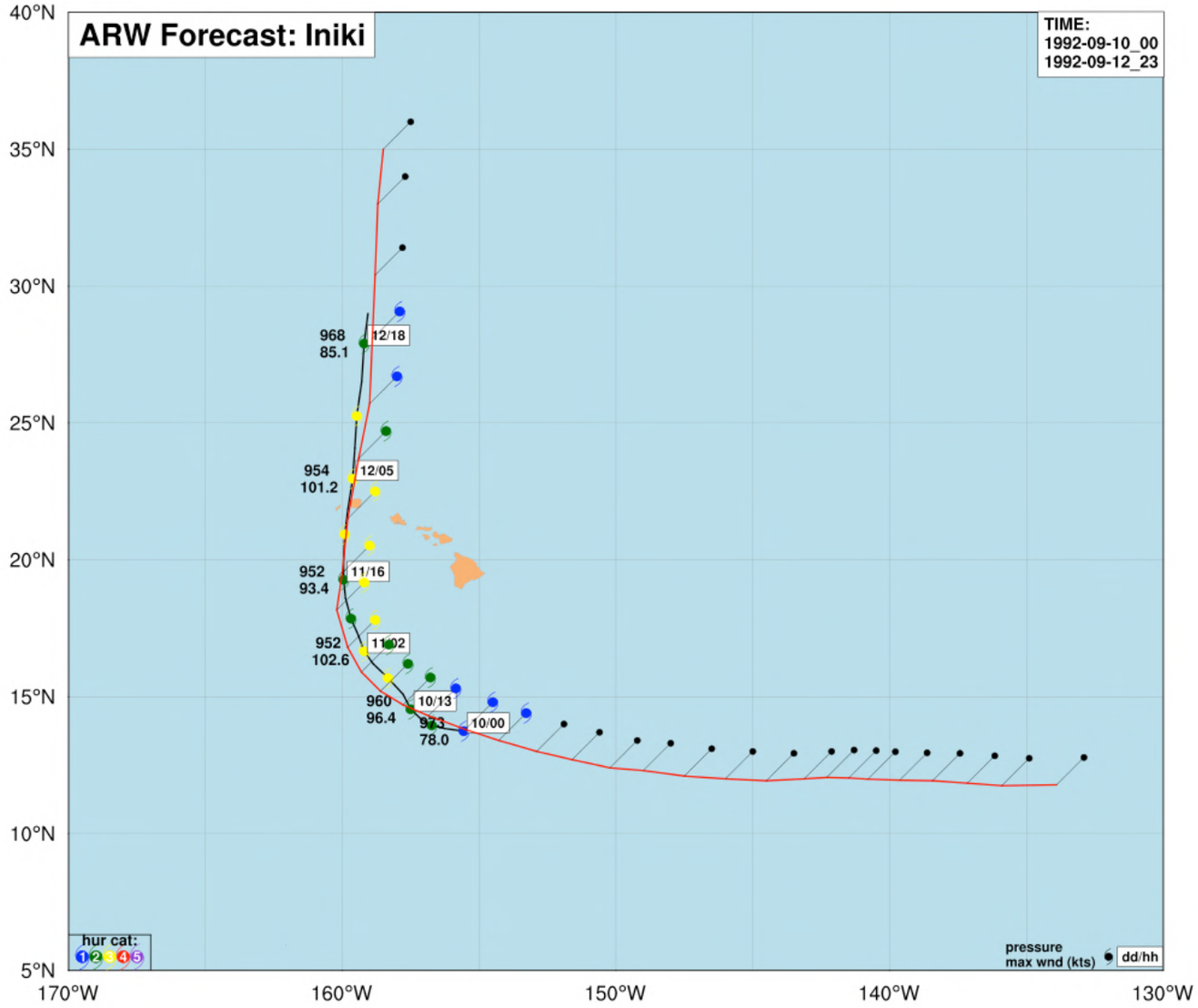


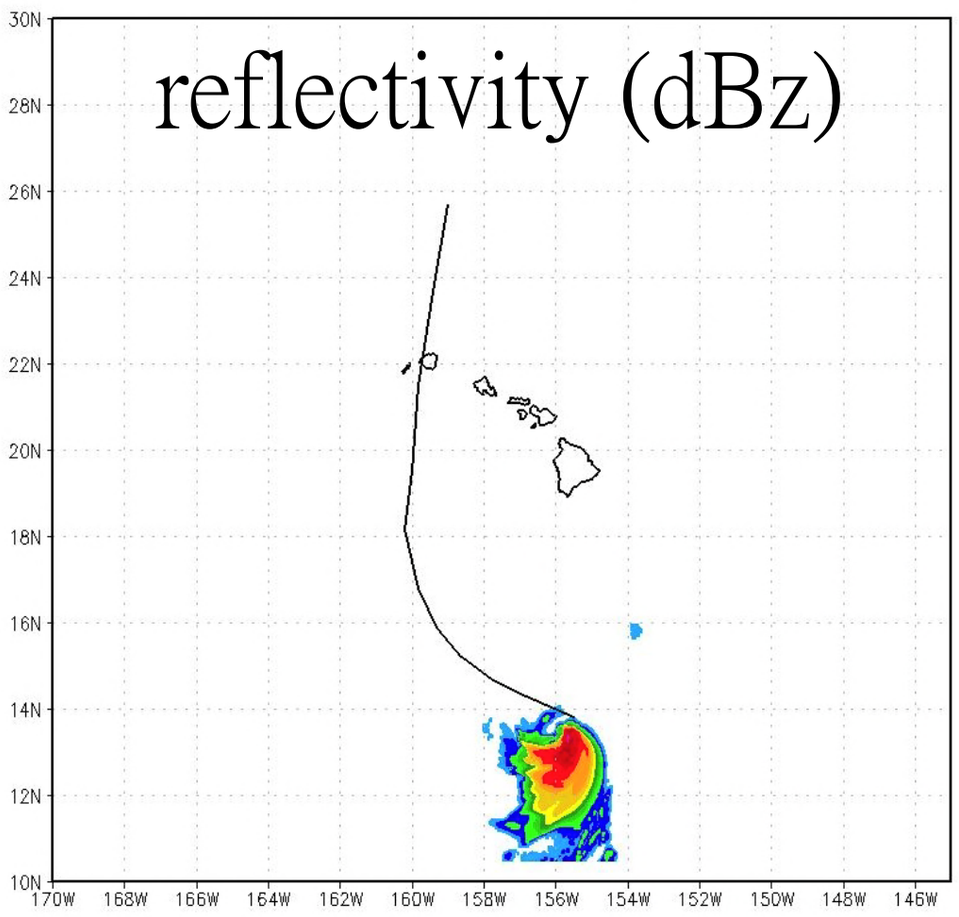
Typhoon (Cat.3) Dujuan
Model init: 0000 01 Sep. 2003
Fcst: 36 hr
Resolution: 2 - 0.5 km

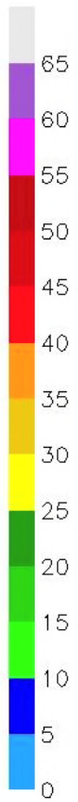


Super Typhoon (Cat.5) Vongfong
Model init: 0000 07 Oct. 2014
Fcst: 72 hr
Resolution: 18 - 6 - 2km



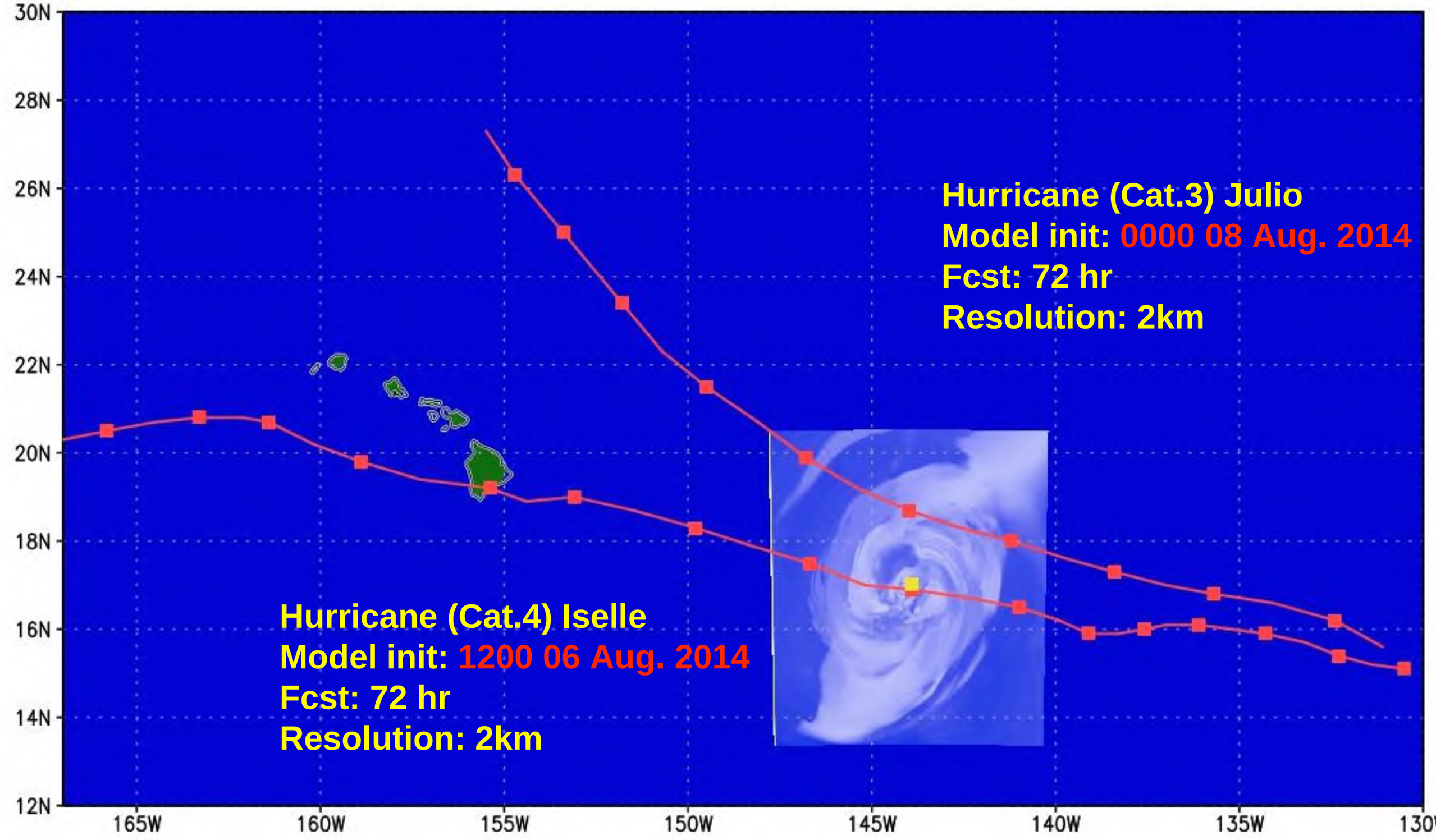






Hurricane (Cat.4) Iniki
Model init: 0000 10 Sep. 1992
Fcst: 72 hr
Resolution: 18 - 6 - 2km

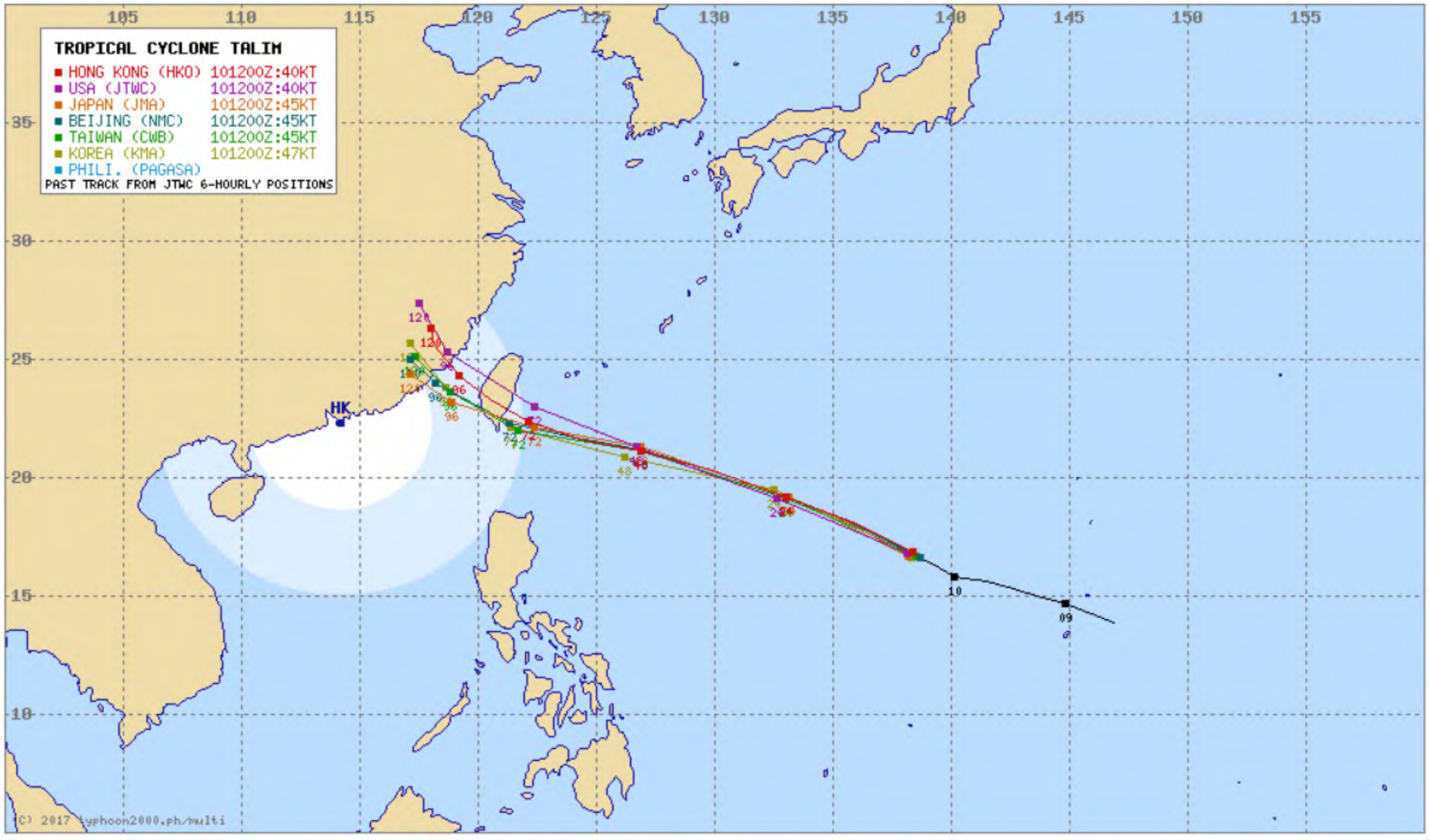
2014 Hurricane Iselle & Julio
Experimental Realtime Forecast



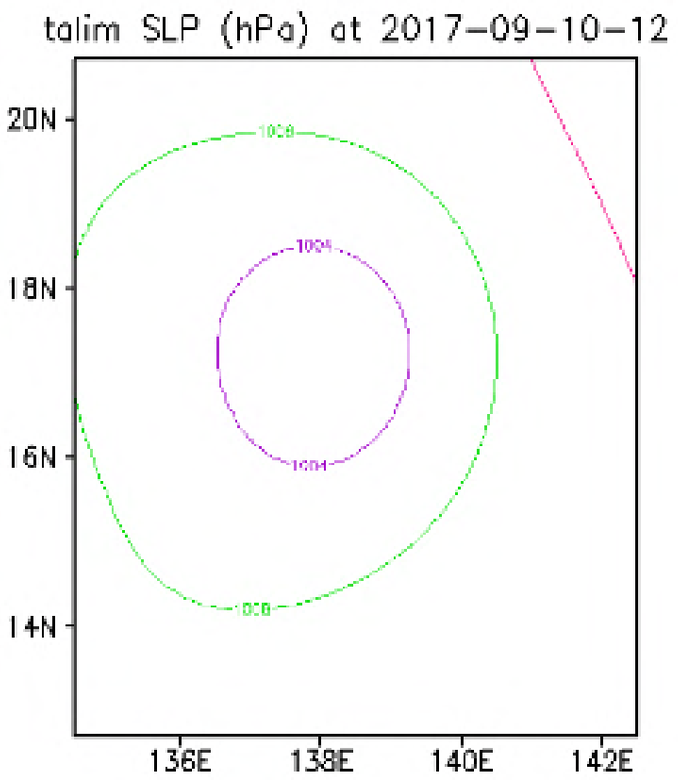
Preliminary results for a recent case

5 days forecast_Talim 1200 UTC Sept. 10, 2017

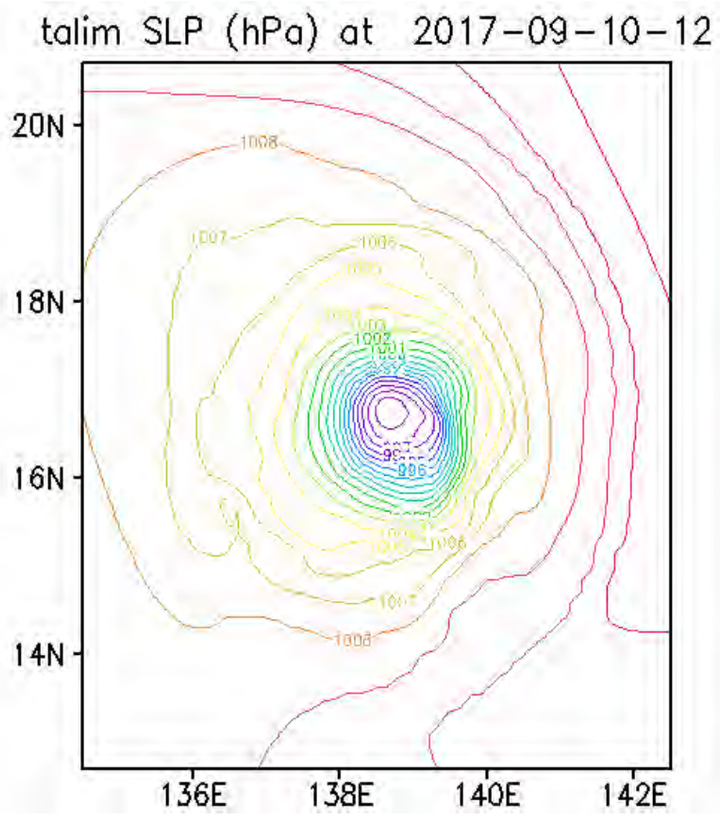
Forecasts from official agencies

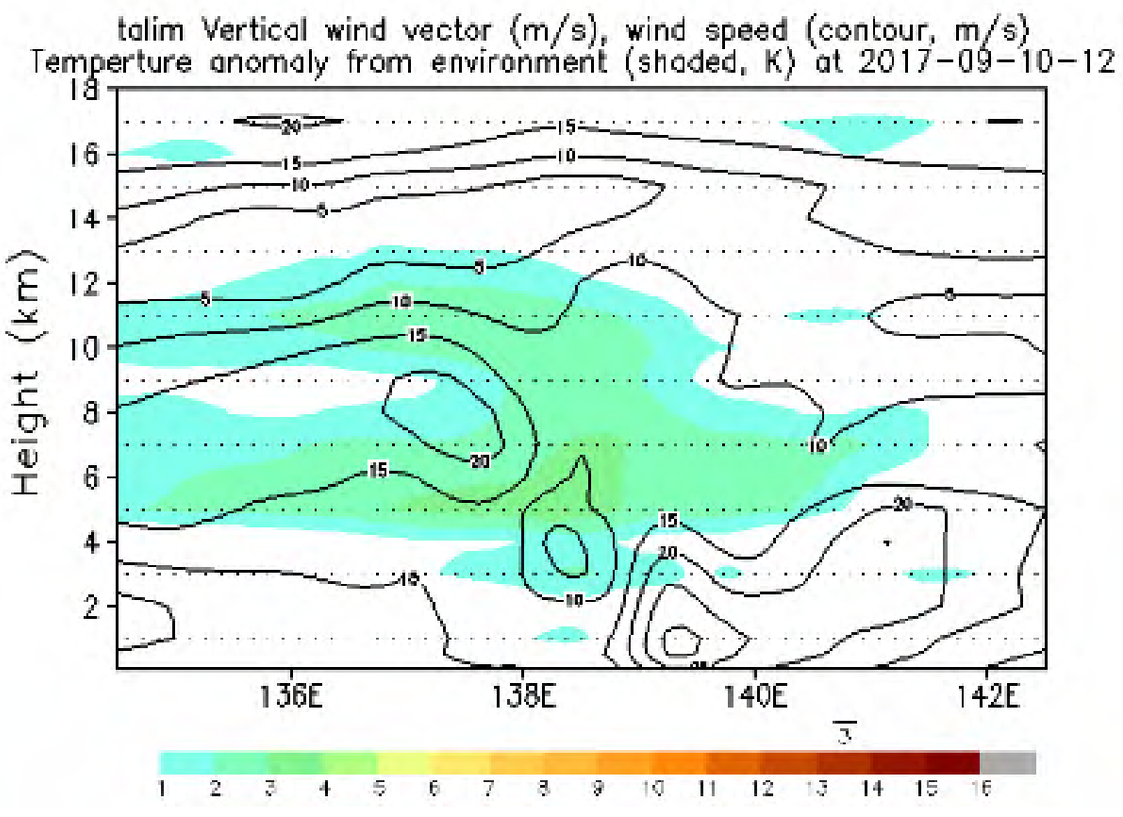


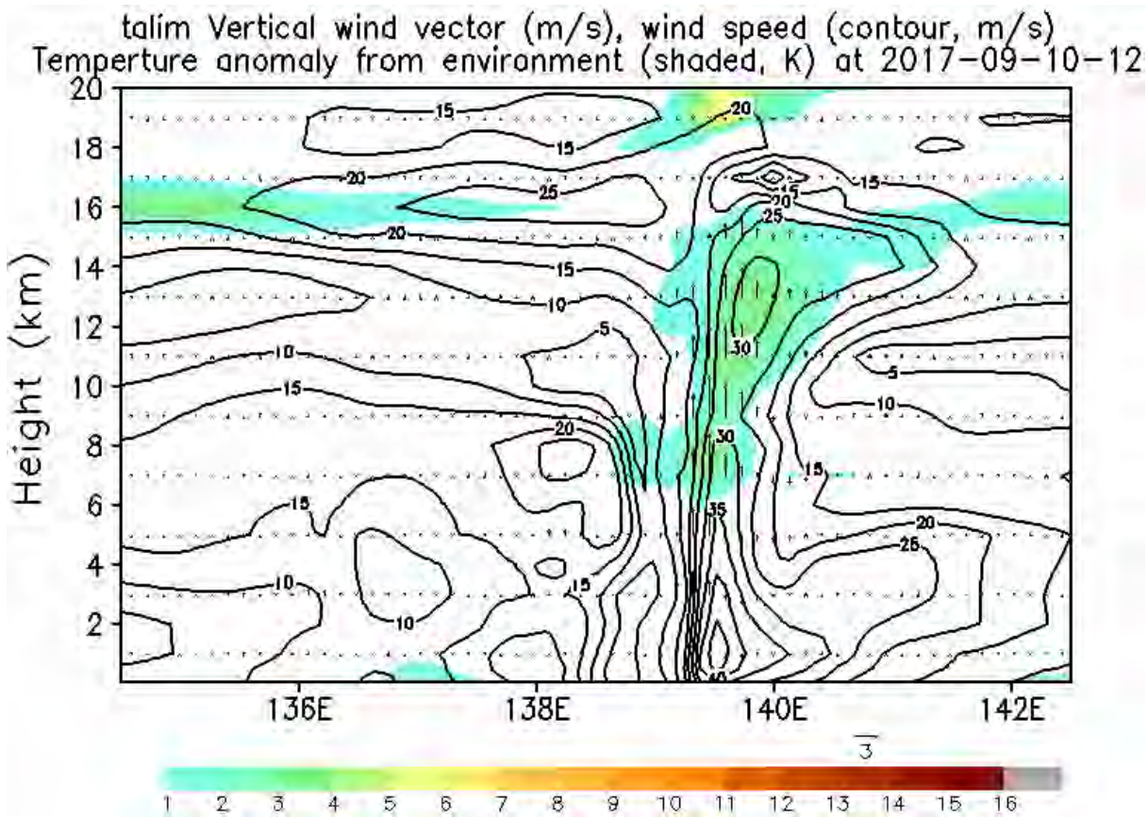
GFS


talim SLP (hPa) at 2017-09-10-12
20N
18N
16N
14N
136E
138E
140E
142E

NC

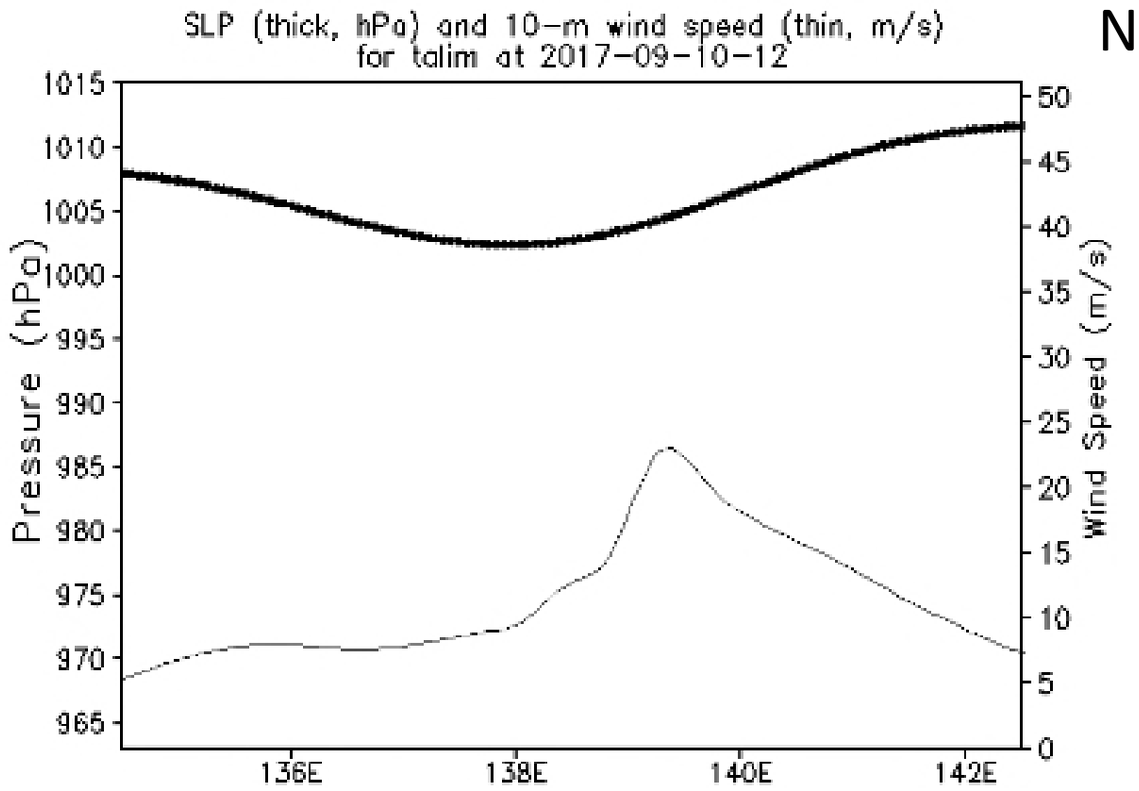

talim SLP (hPa) at 2017-09-10-12
20N
18N
16N
14N
136E
138E
140E
142E


talim Vertical wind vector (m/s), wind speed (contour, m/s)
Temperture anomaly from environment (shaded, K) at 2017-09-10-12
Height (km)
136E
138E
140E
142E
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

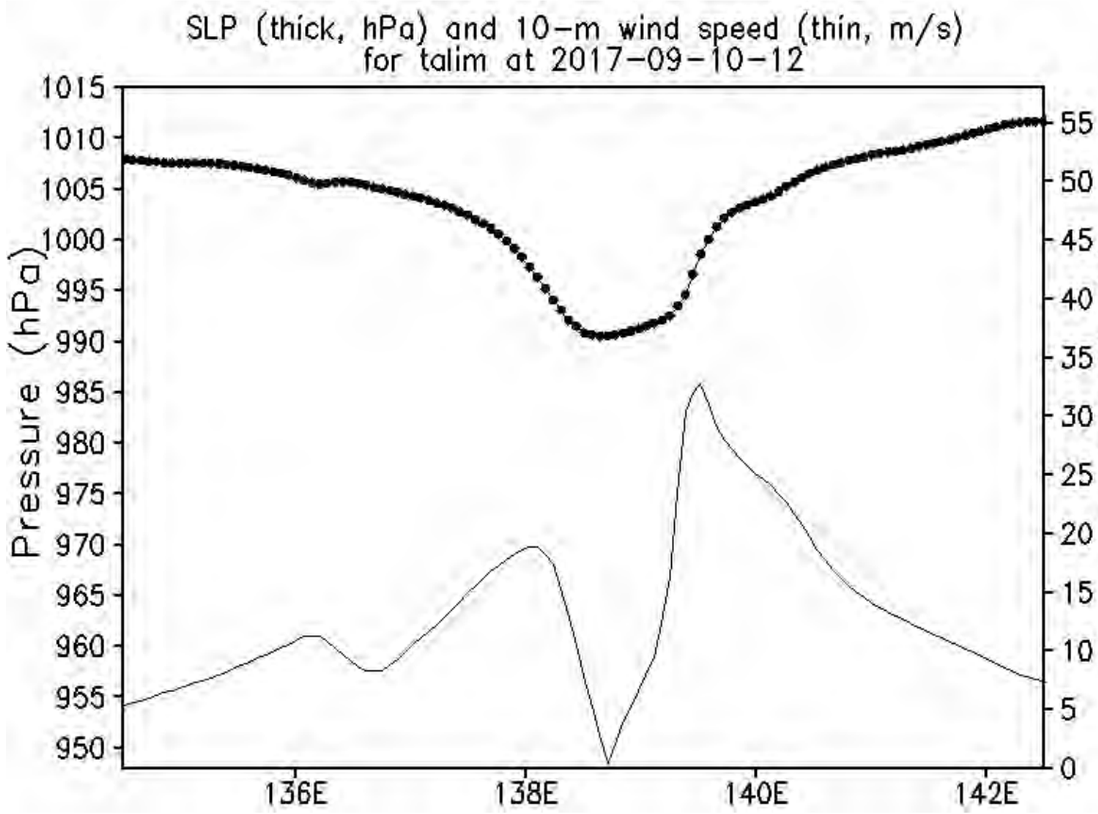

talim Vertical wind vector (m/s), wind speed (contour, m/s)
Temperture anomaly from environment (shaded, K) at 2017-09-10-12
Height (km)
136E
138E
140E
142E
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Talim (2017)

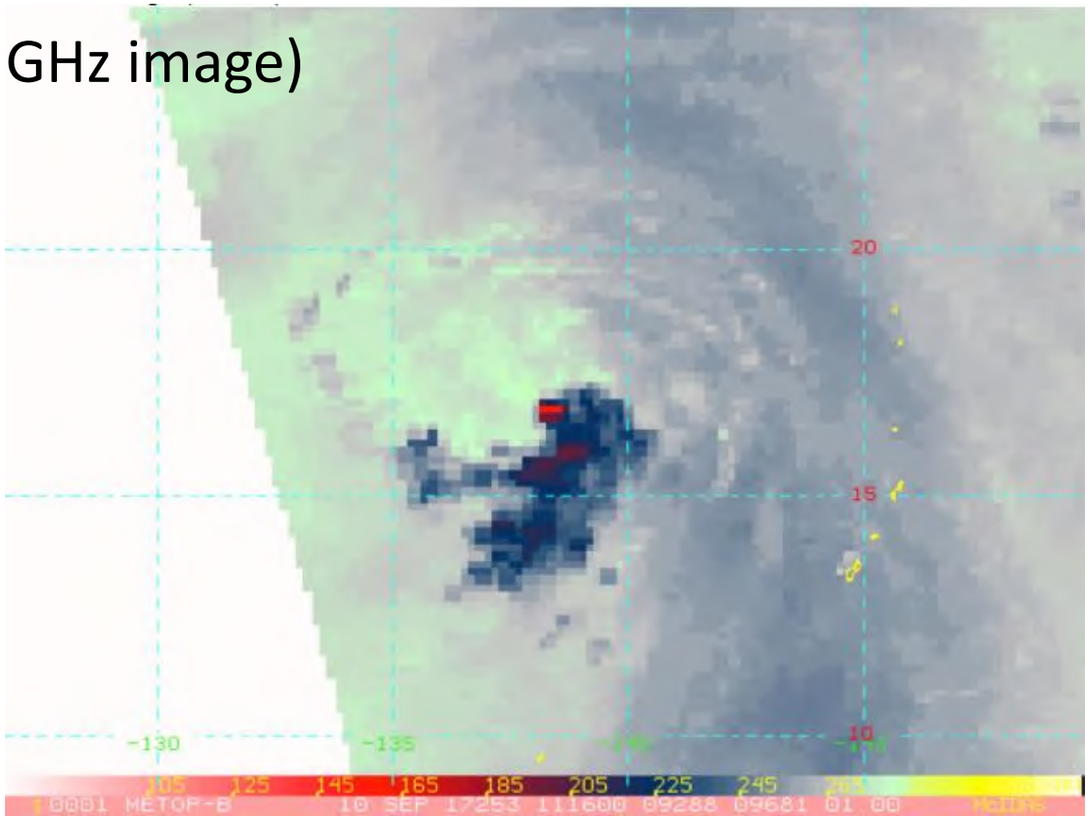
GFS



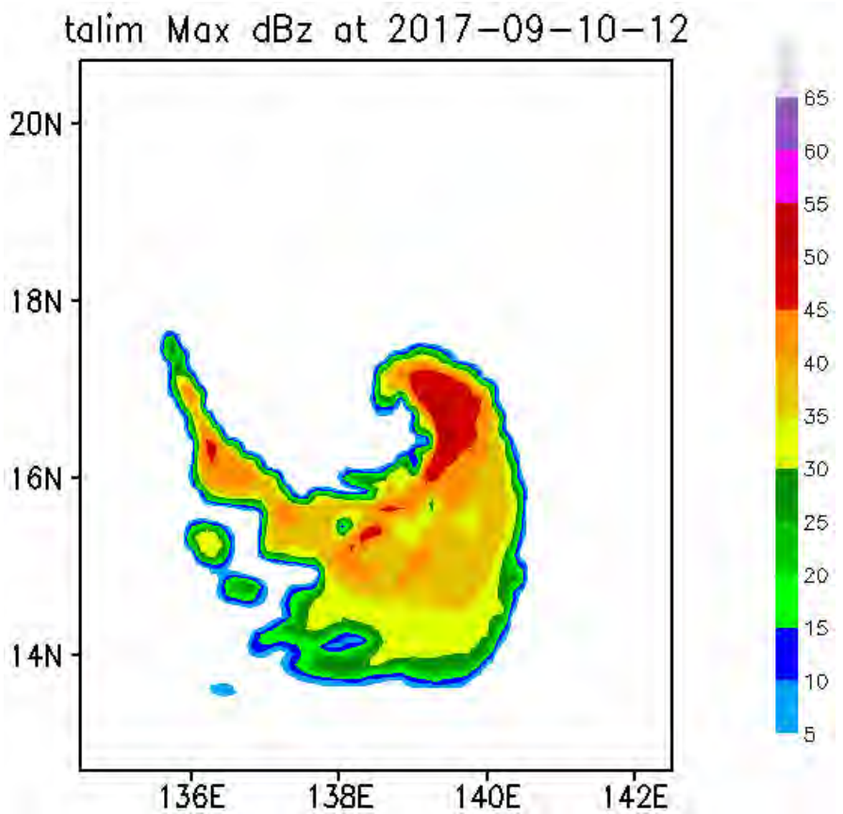
NC



Obs (89 GHz image)



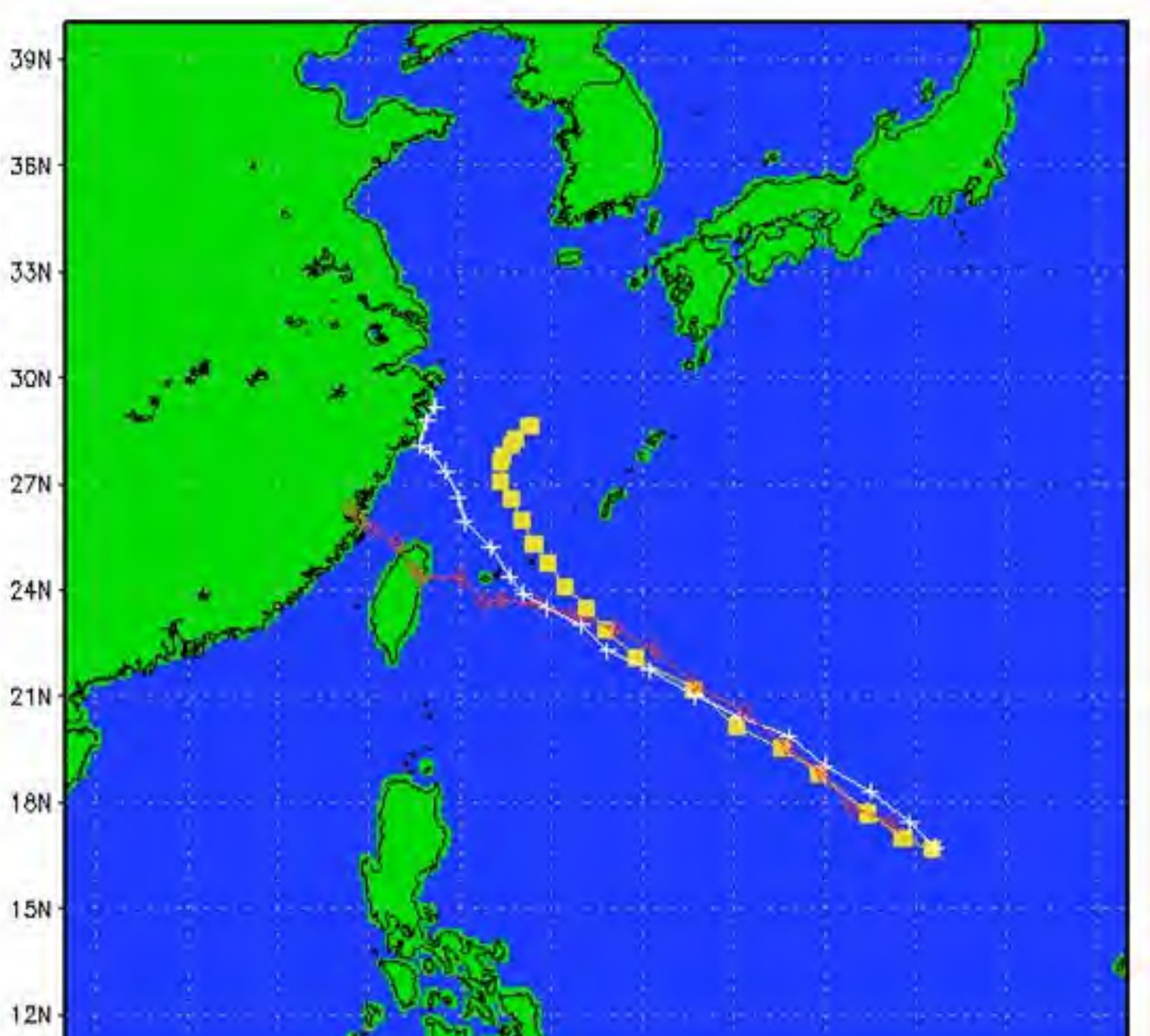
NC



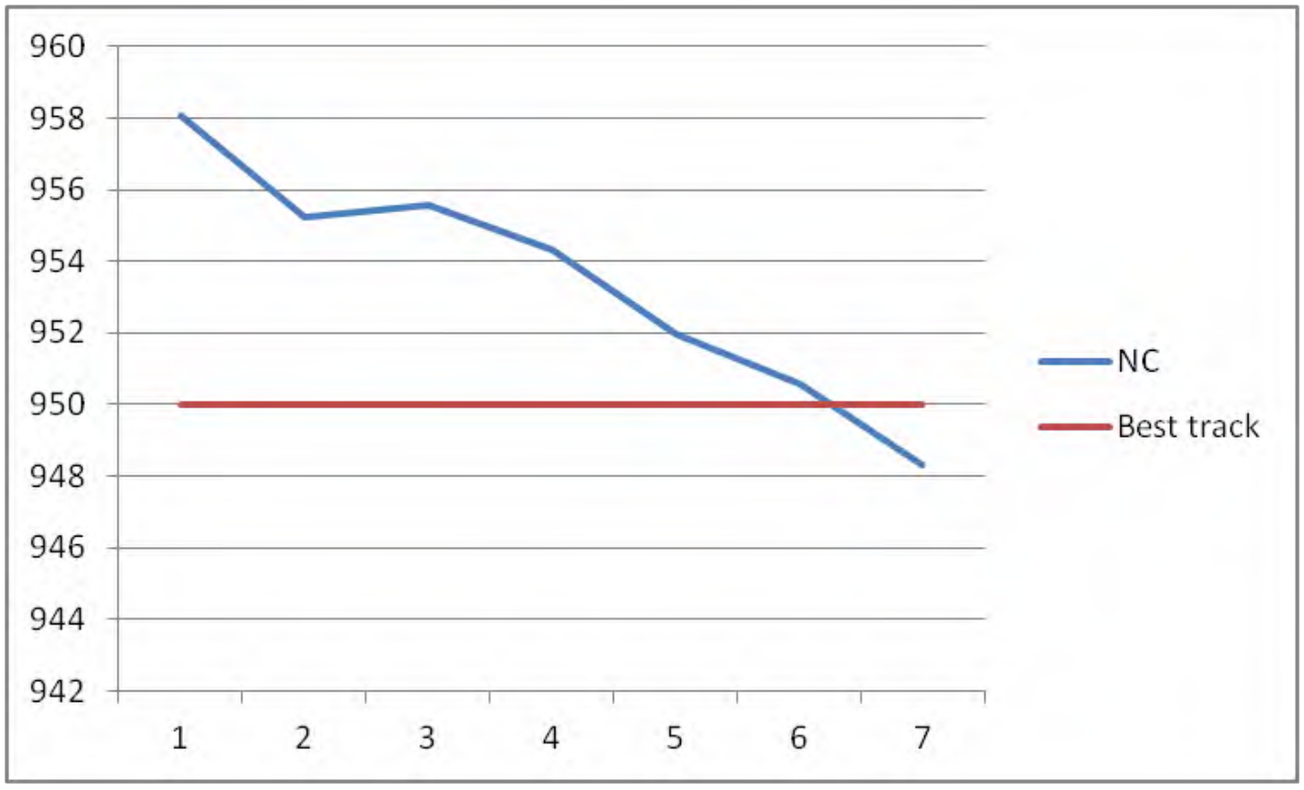
Red: COAMPS

Yellow: CWB best track

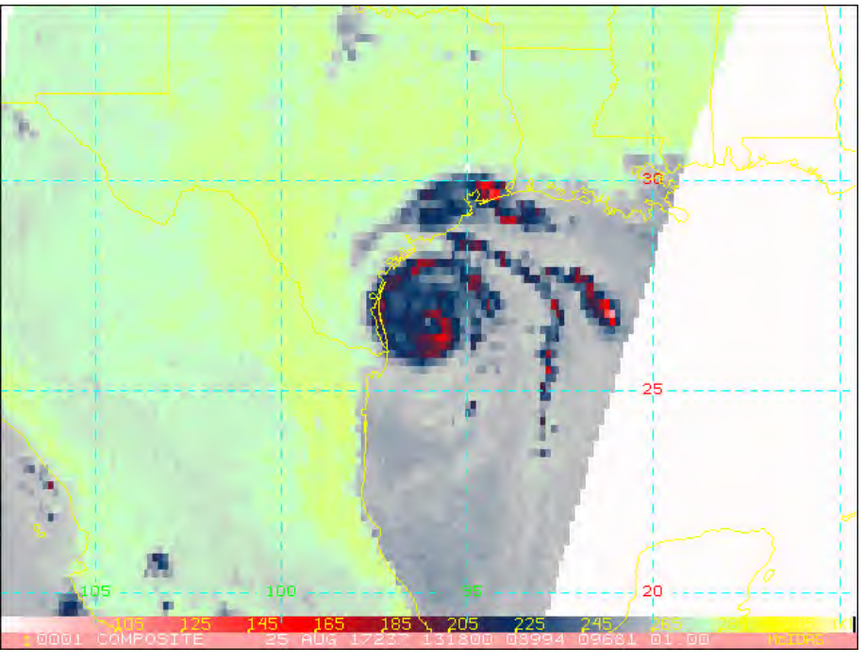
White: NC

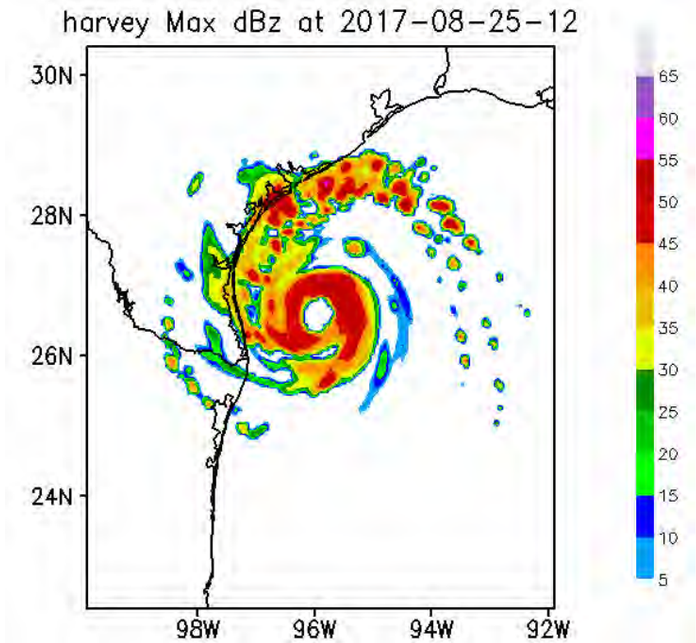


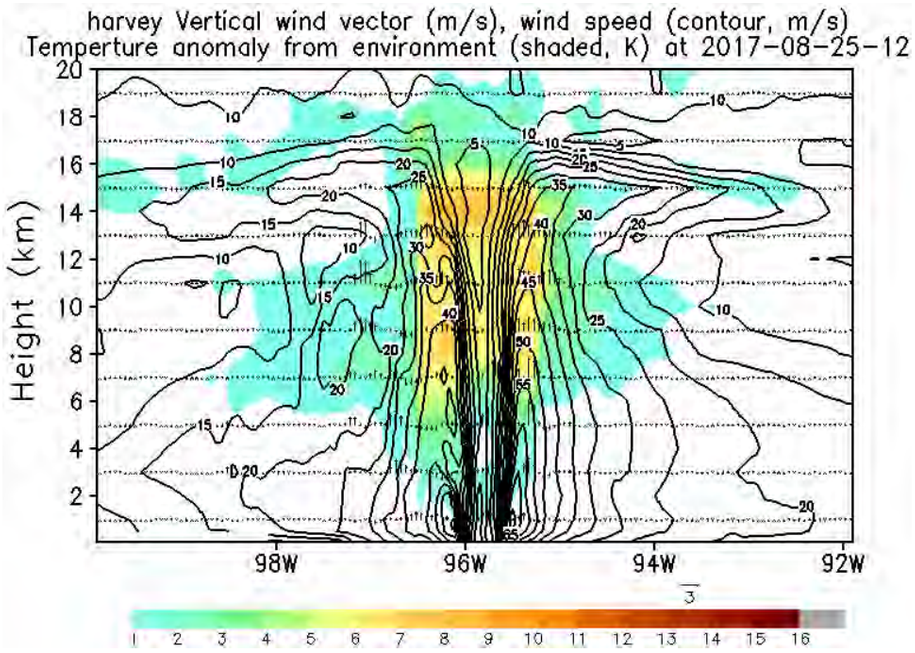
TC Harvey (2017)
0825_12_R600

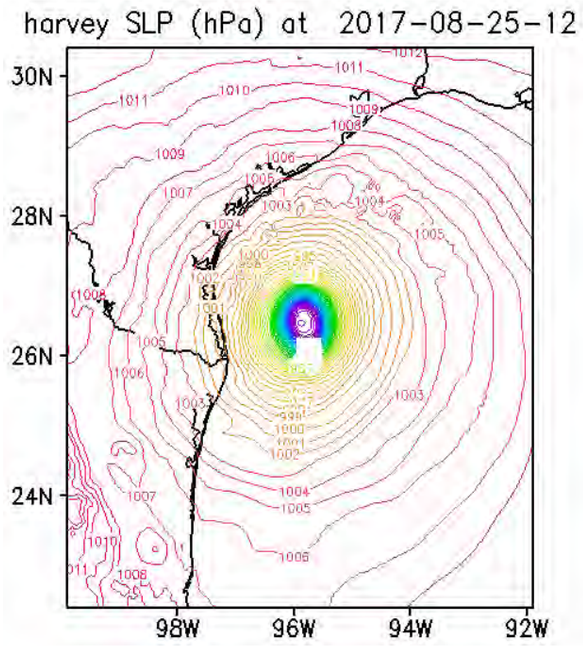


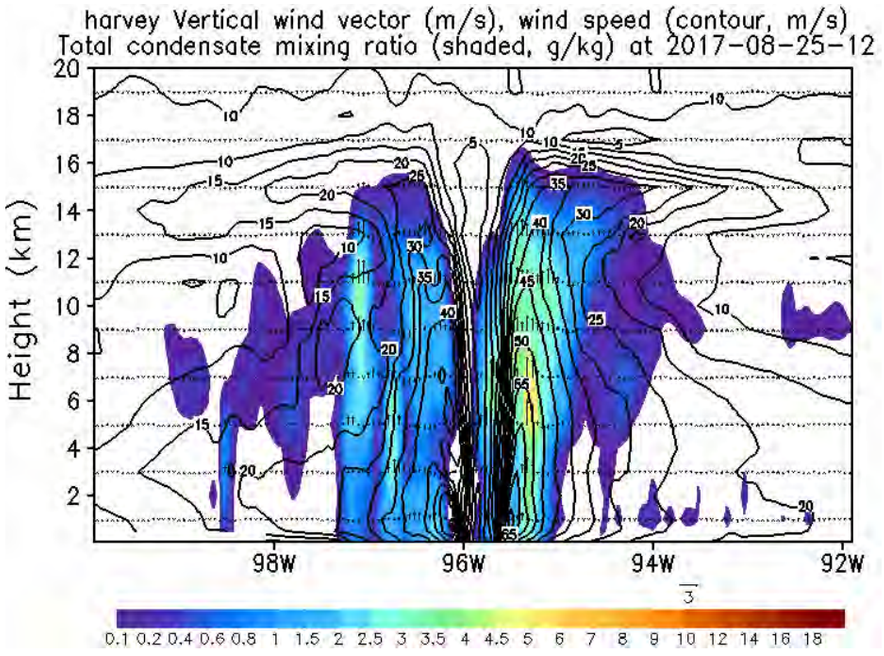
0825_12_R600

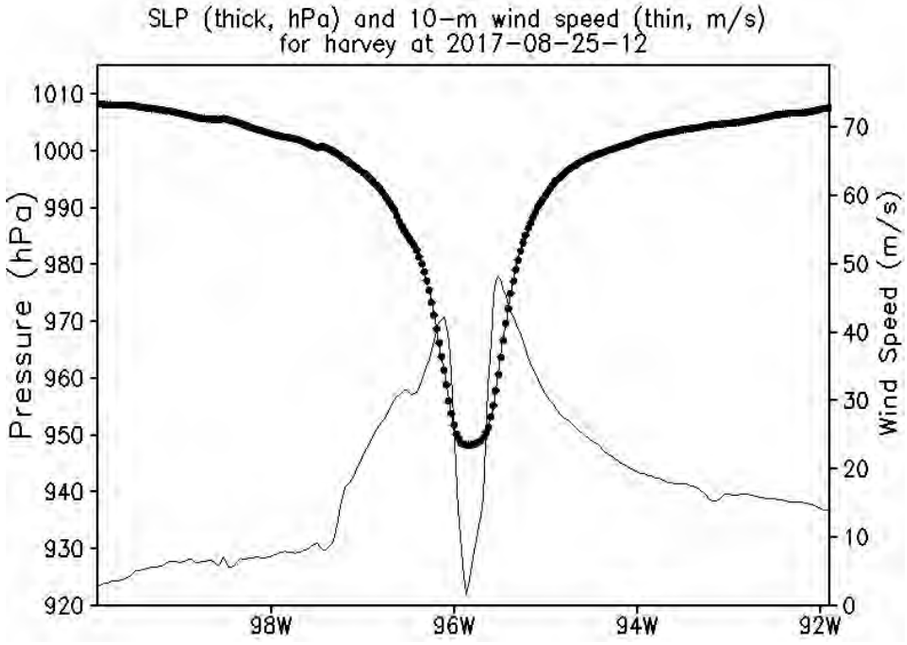

0001 COMPOSITE
25 AUG 1725 131800 03994 09681 01 00


harvey Max dBz at 2017-08-25-12
30N
28N
26N
24N
98W
96W
94W
92W
65
60
55
50
45
40
35
30
25
20
15
10
5

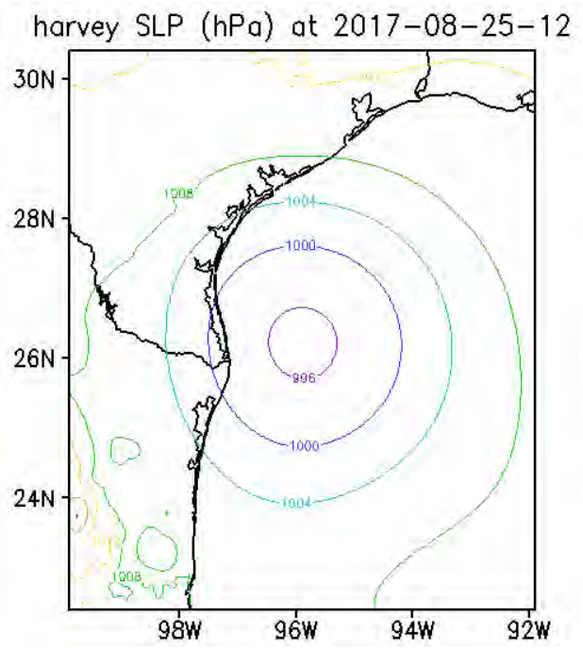

harvey Vertical wind vector (m/s), wind speed (contour, m/s)
Temperture anomaly from environment (shaded, K) at 2017-08-25-12
Height (km)
98W
96W
94W
92W
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

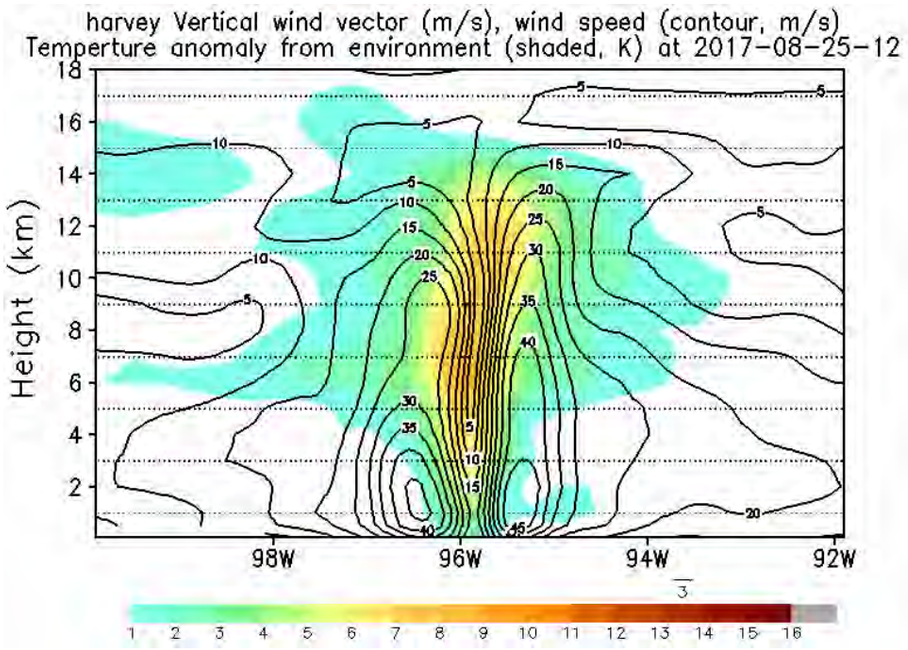

harvey SLP (hPa) at 2017-08-25-12
30N
28N
26N
24N
98W
96W
94W
92W

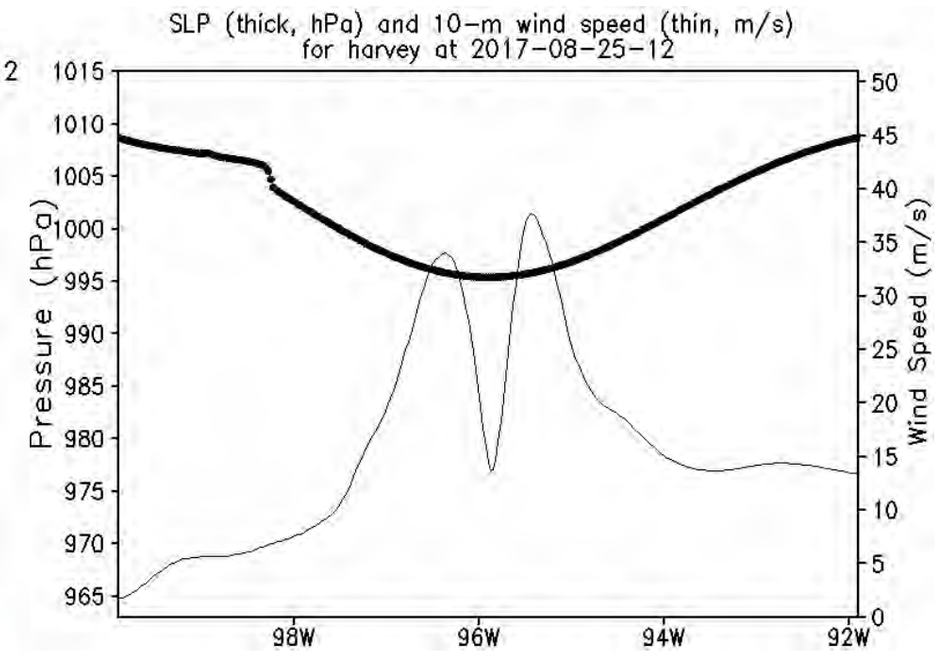

harvey Vertical wind vector (m/s), wind speed (contour, m/s)
Total condensate mixing ratio (shaded, g/kg) at 2017-08-25-12
Height (km)
98W
96W
94W
92W
0.1 0.2 0.4 0.6 0.8 1 1.5 2 2.5 3 3.5 4 4.5 5 6 7 8 9 10 12 14 16 18


SLP (thick, hPa) and 10-m wind speed (thin, m/s)
for harvey at 2017-08-25-12
Pressure (hPa)
Wind Speed (m/s)
98W
96W
94W
92W

0825_12_WRF(IC=GFS)

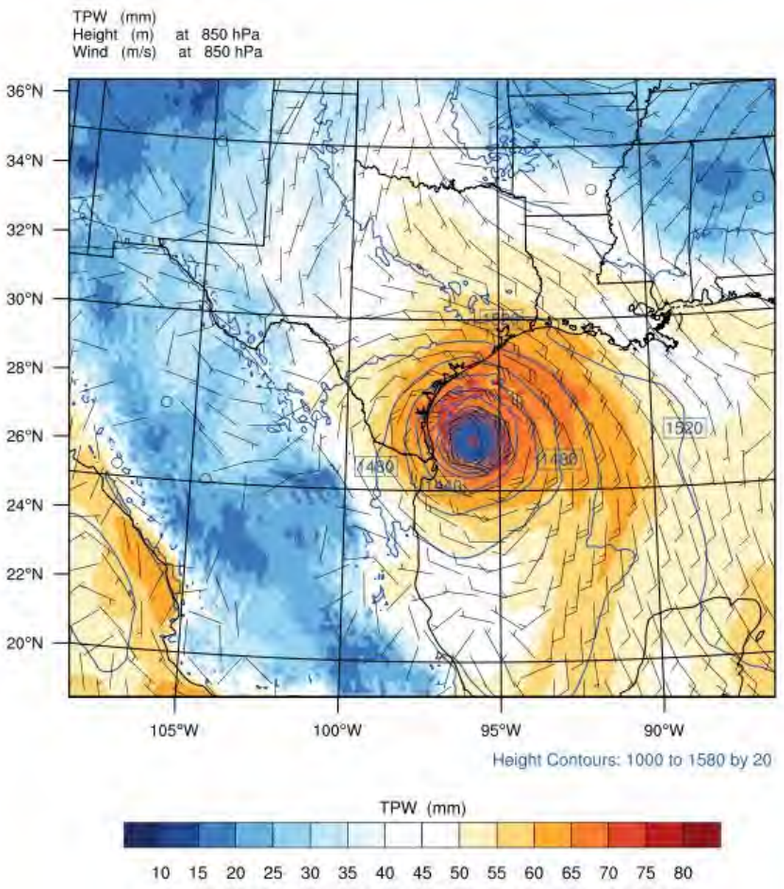




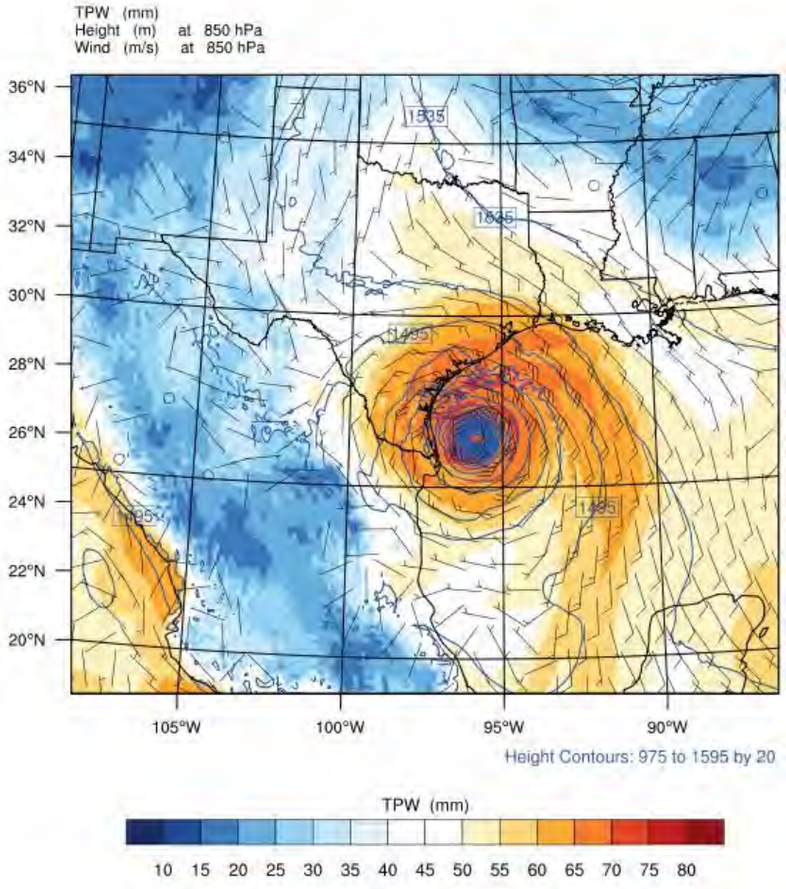


800hPa IC TPW_wind_Geopt

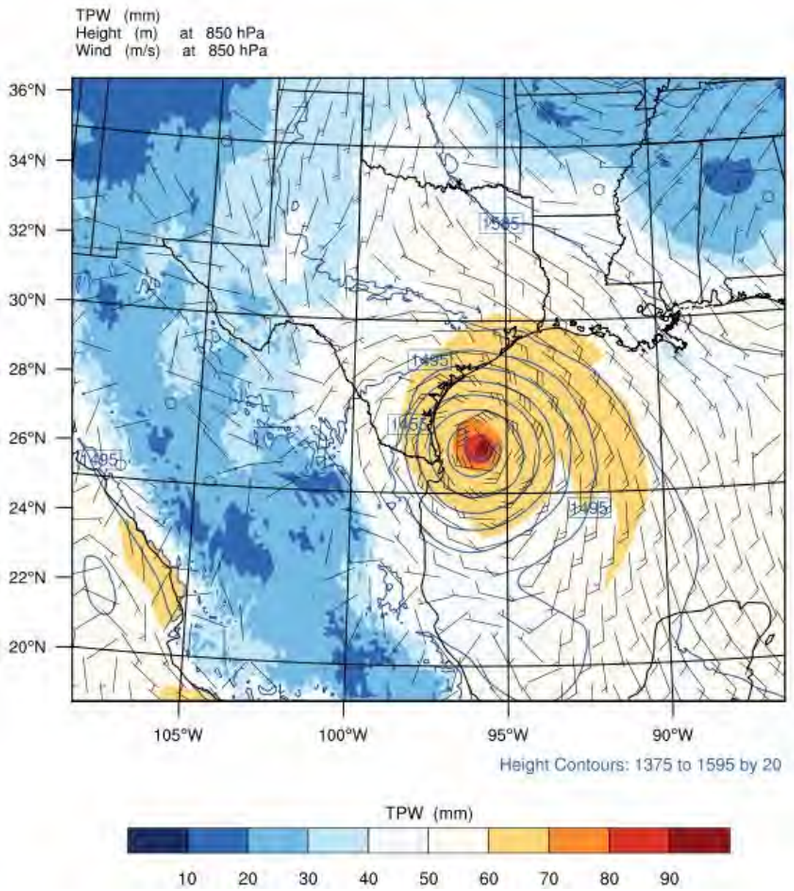
R400



R600



WRF (IC=GFS)



Conclusion

For all cases considered (including those cases presented by NC2011 and NC2014), the scheme works well in predicting track, intensity and structure for storms with different intensities at different stages of their life cycle over the Northwestern Pacific. This is because at the model initial time, the initial storm intensity and structure are well adjusted to the environmental conditions in which it is embedded and well adapted to the model employed.

Observations needed

1. Better storm environment [including the southwesterly monsoon flow (T,q, U, V profiles)] to spin up the vortex.
2. Better TC intensity (Pmin and Vmax) for initialization

References

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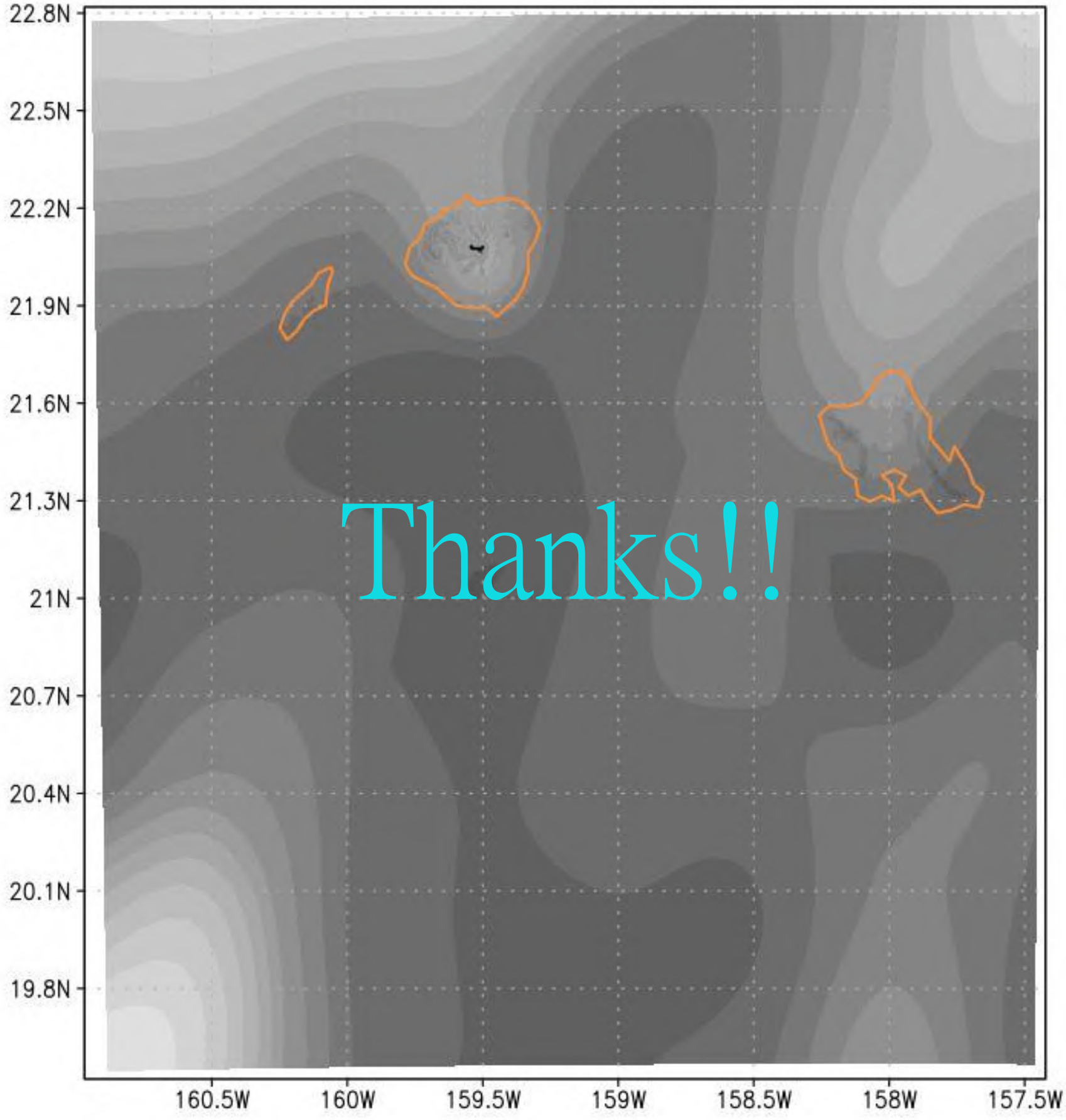
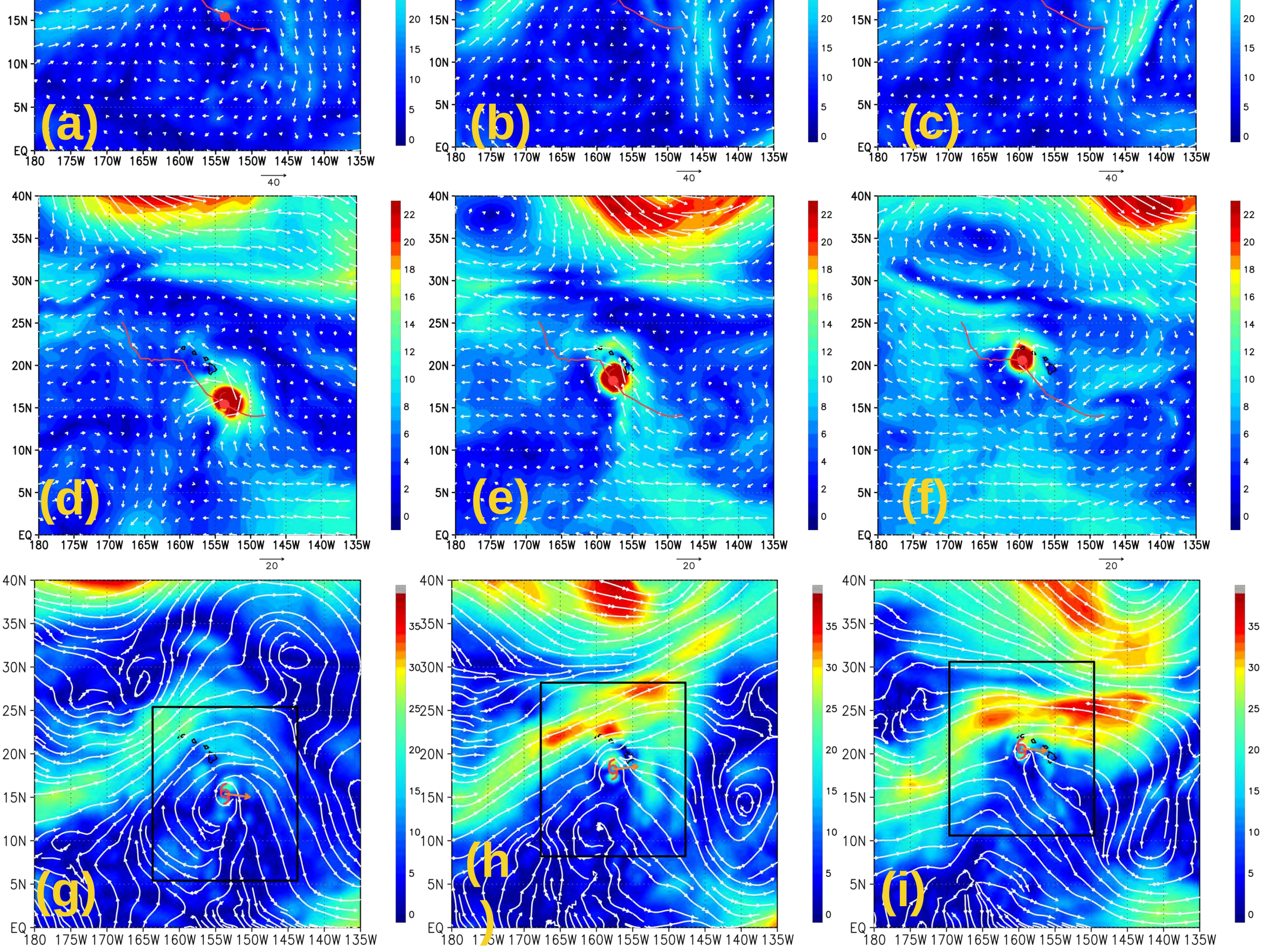
- Kidder, S. Q., M. D. Goldberg, R. M. Zehr, M. DeMaria, J. F. W. Purdom, C. S. Velden, N. C. Grody, and S. J. Kusselson, 2000: Satellite analysis of tropical cyclones using the Advanced Microwave Sounding Unit (AMSU). *Bull. Amer.Meteor. Soc.*, 81, 1241 – 1260, doi:10.1175/1520-0477(2000)081,1241:SAOTCU.2.3.CO;2.

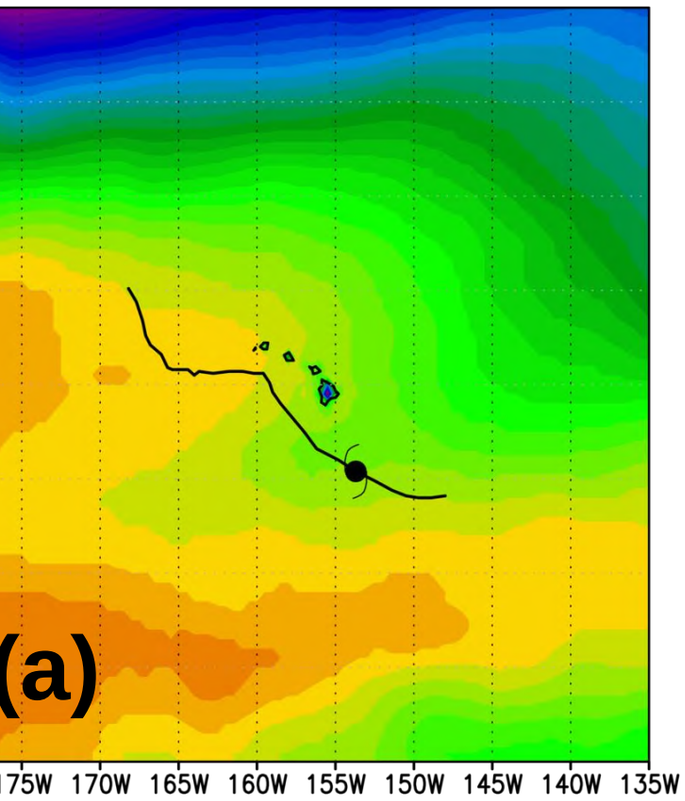
- Nguyen, H. V., and Y.-L. Chen, 2011: High-resolution initialization and simulations of Typhoon Morakot (2009). *Mon. Wea. Rev*., 139, 1463 – 1491, doi:10.1175/2011MWR3505.1.

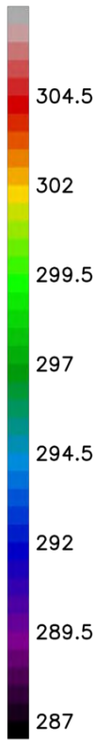
- Nguyen, H.V., and Y.-L. Chen, 2014: Improvements to a Tropical Cyclone Initialization Scheme and Impacts on Forecasts. *Mon. Wea. Rev.*, 142, 4340-4356

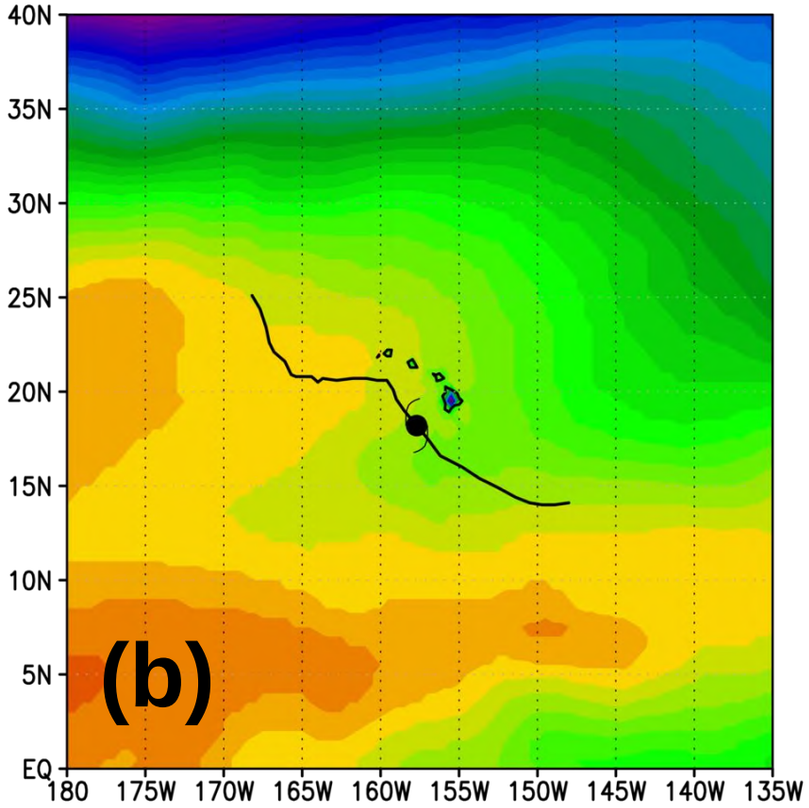
- Velden, C. S., B. M. Goodman, and R. T. Merrill, 1991: Western North Pacific tropical cyclone intensity estimation from NOAA polar-orbiting satellite microwave data. *Mon. Wea. Rev*., 119, 159 – 168, doi:10.1175/1520-0493(1991)119,0159: WNPTCI.2.0.CO;2.

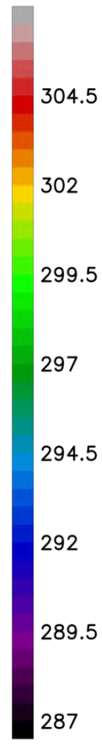

22.8N
22.5N
22.2N
21.9N
21.6N
21.3N
21N
20.7N
20.4N
20.1N
19.8N
160.5W
160W
159.5W
159W
158.5W
158W
157.5W
Thanks!!

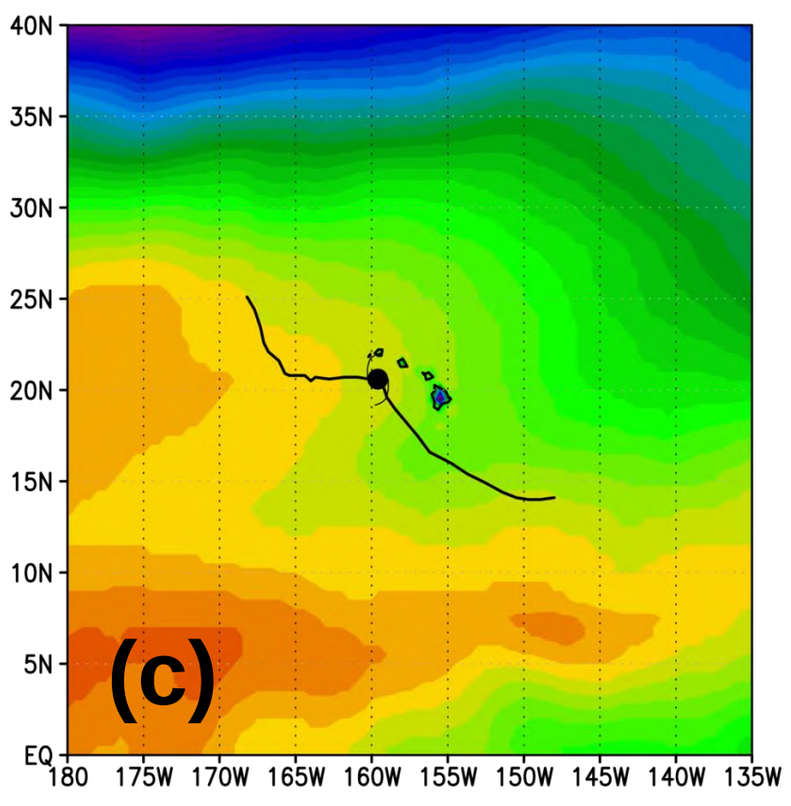

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
EQ
5N
10N
15N
20N
25N
30N
35N
40N
180 175W 170W 165W 160W 155W 150W 145W 140W 135W
40
20

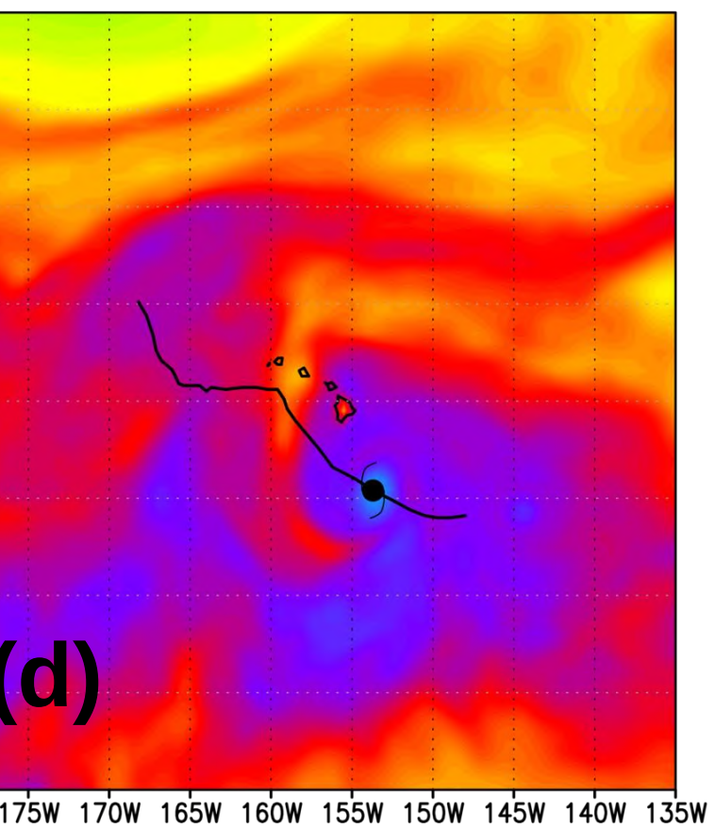

(a)
175W 170W 165W 160W 155W 150W 145W 140W 135W

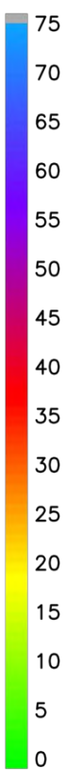

304.5
302
299.5
297
294.5
292
289.5
287


(b)
40N
35N
30N
25N
20N
15N
10N
5N
EQ
180 175W 170W 165W 160W 155W 150W 145W 140W 135W


304.5
302
299.5
297
294.5
292
289.5
287


(c)
40N
35N
30N
25N
20N
15N
10N
5N
EQ
180 175W 170W 165W 160W 155W 150W 145W 140W 135W


(d)
175W 170W 165W 160W 155W 150W 145W 140W 135W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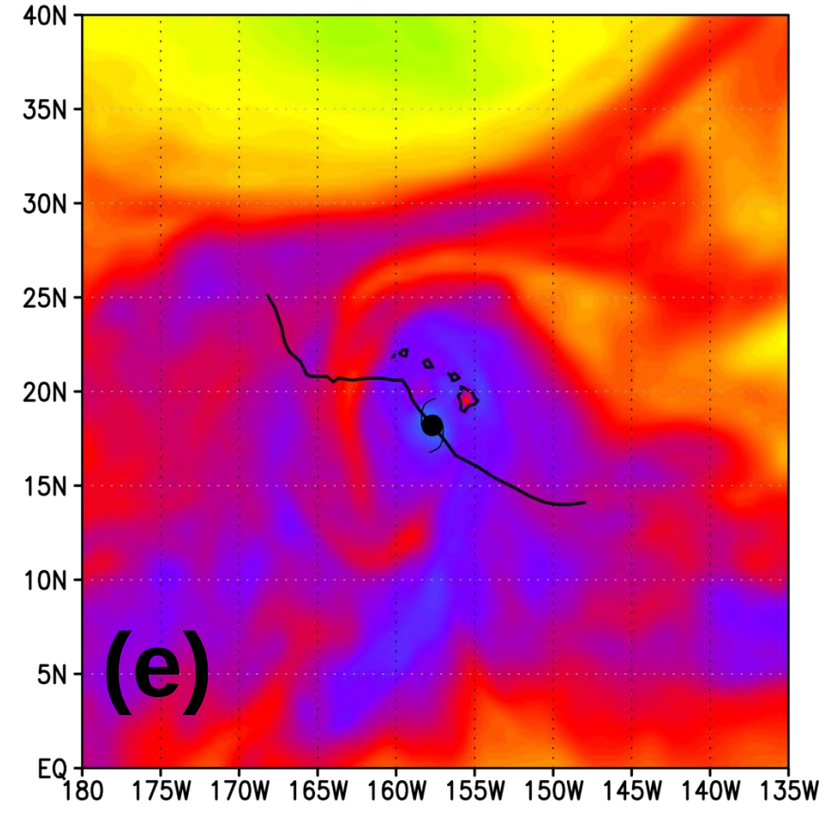
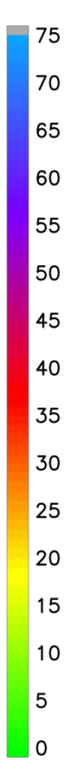

(e)
40N
35N
30N
25N
20N
15N
10N
5N
EQ
180 175W 170W 165W 160W 155W 150W 145W 140W 135W


75
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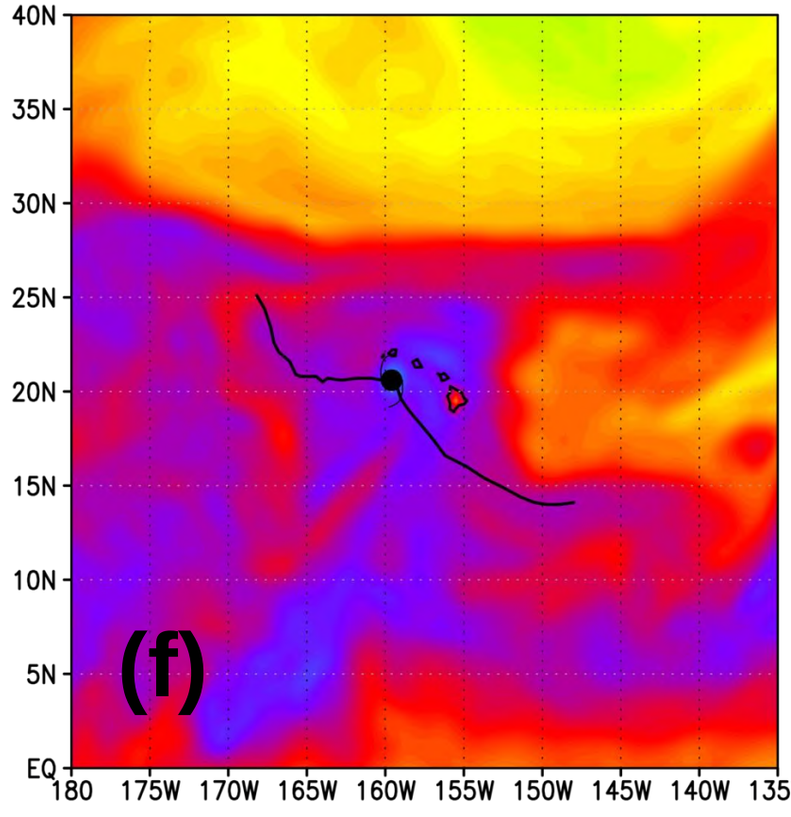
(f)
40N
35N
30N
25N
20N
15N
10N
5N
EQ
180 175W 170W 165W 160W 155W 150W 145W 140W 135