# 中央氣象局TWRF颱風數值預報系統對西北太平洋颱風預測能力之評估與改進研究

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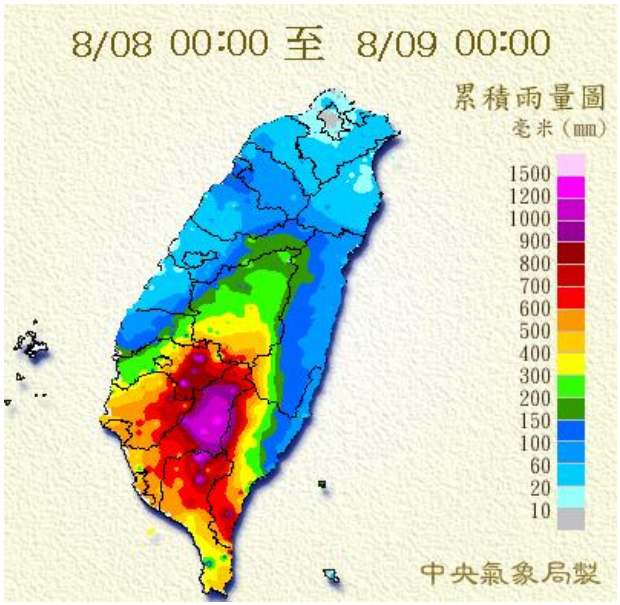
中央氣象局

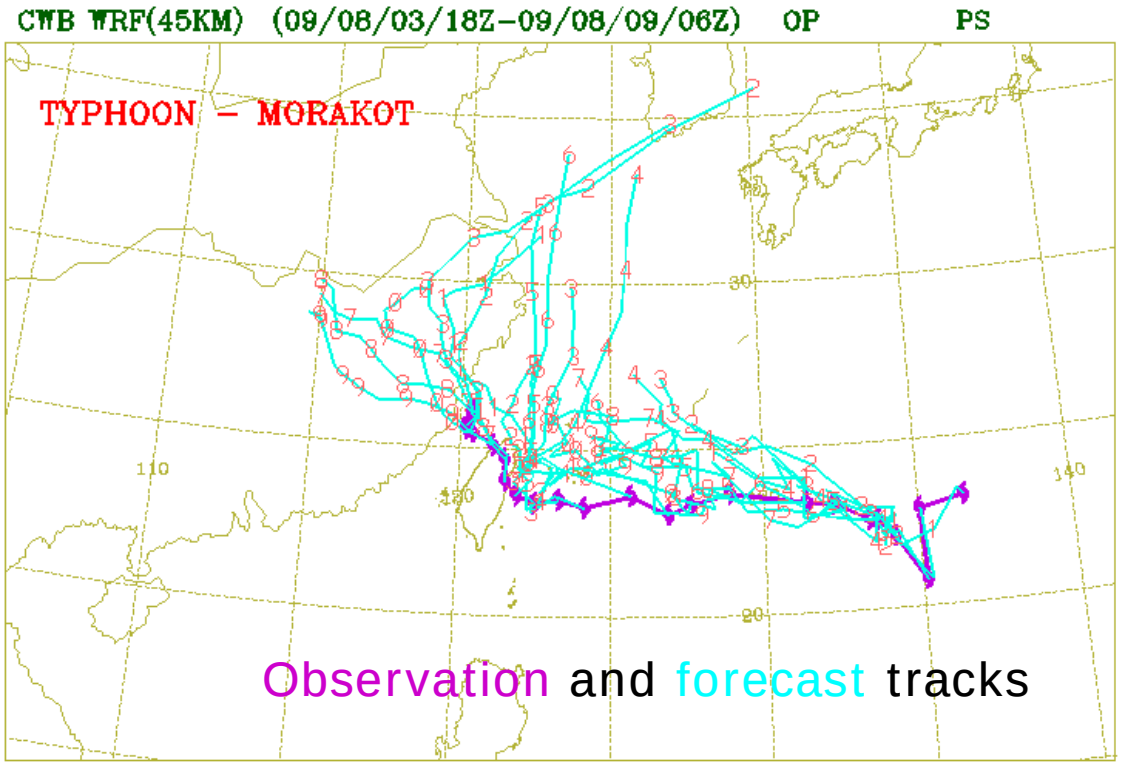
2016.10.04

# Motivation

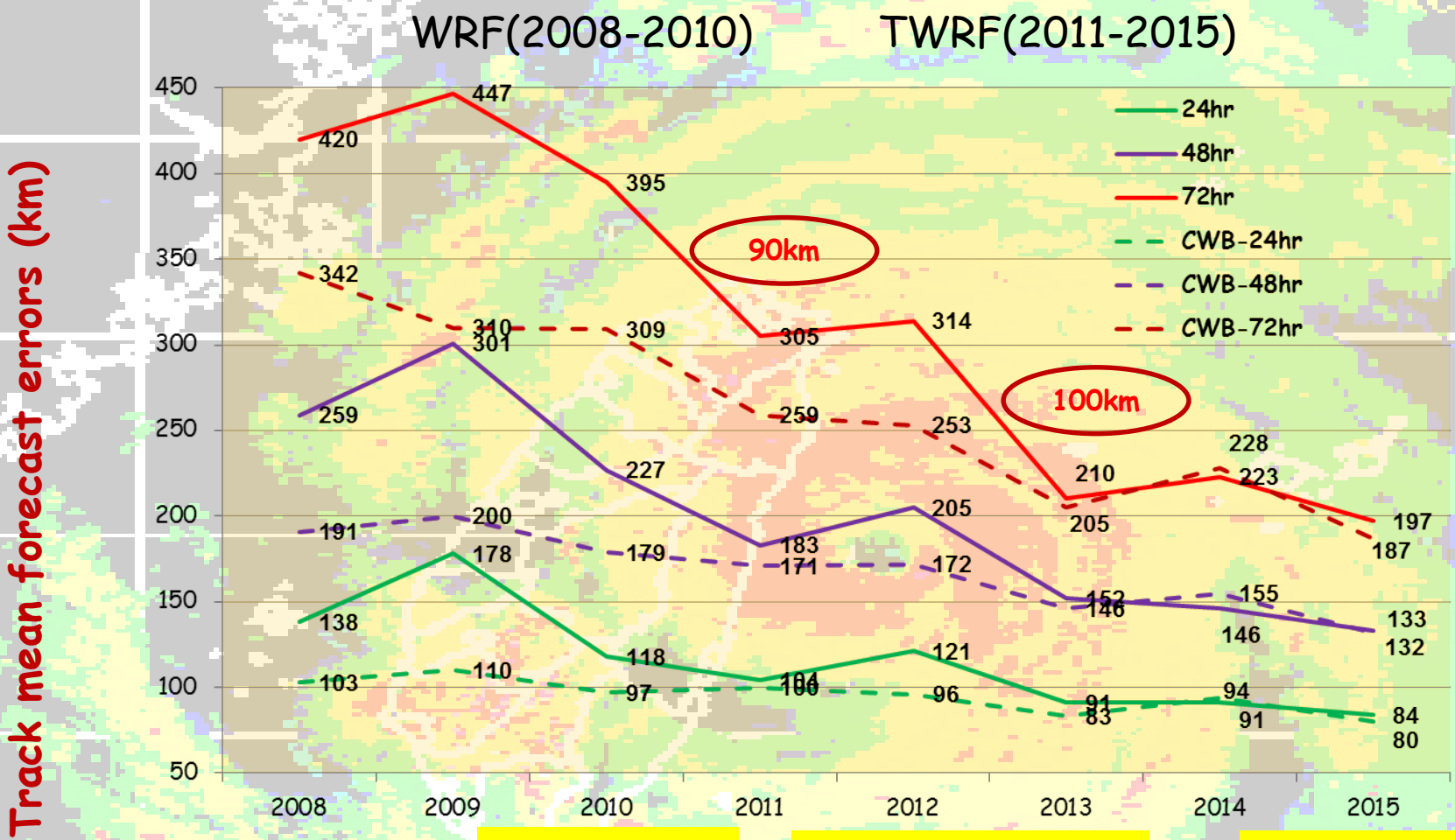
∗ TC forecast Error of the operational CWB WRF was relatively unsatisfied forecast in 2009




**>1200 mm Rainfall in 24 hours**
**>2700 mm Rainfall in 72 hours**
**Typhoon Morakot (2009)**



# Comparison between TWRF & CWB forthe TC Track Forecast Errors




Operation

TC Relocation
CPS: GD -> KF

TC bogus

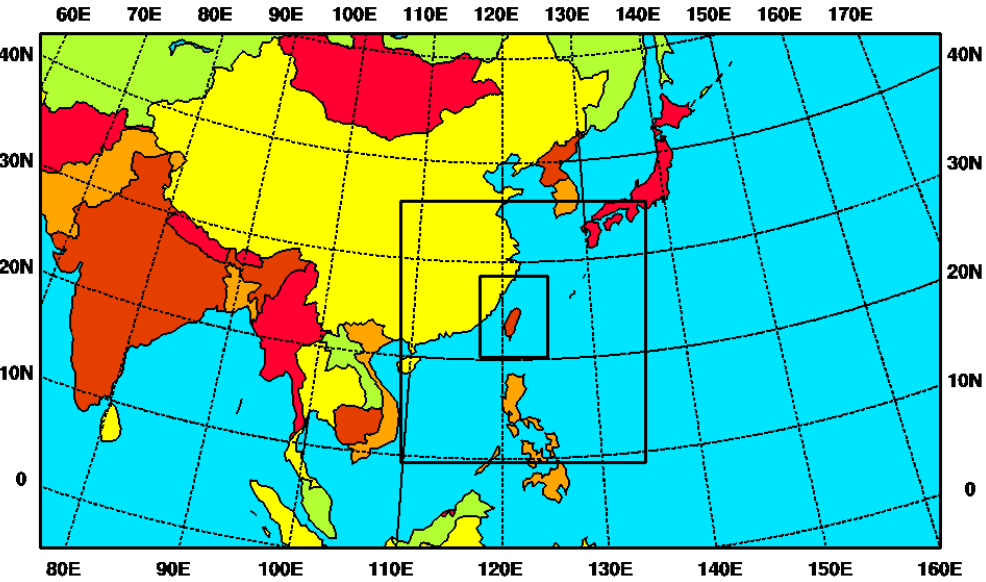
Partial cycling
Outer loop
New trigger KF

New TC initialization

Blending
NCEPGFS & TWRF
45km →→ 15km

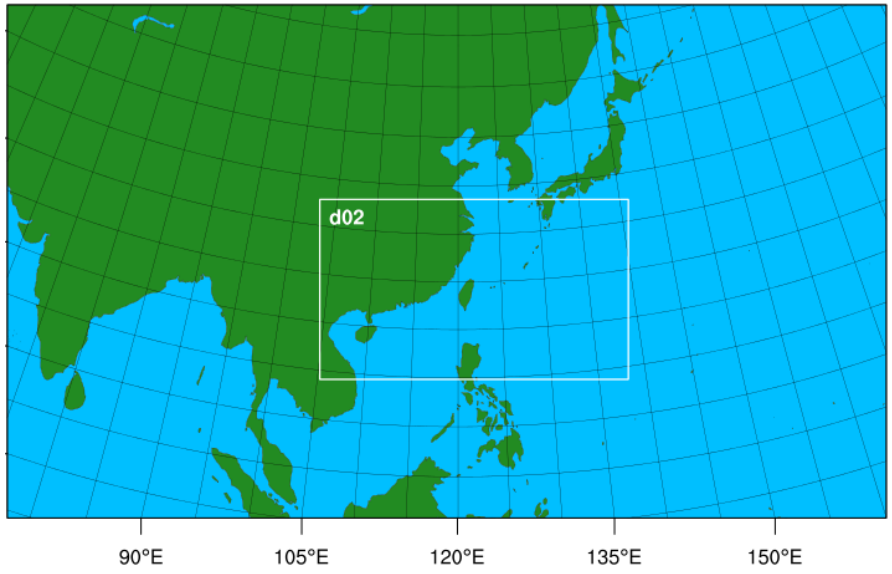
Two-way interaction

# TWRF1.5




D1: 222*128 (45-km)
D2: 184*196 (15-km)
D3: 151*181 (5-km)
45 levels in the vertical

# TWRF2.0



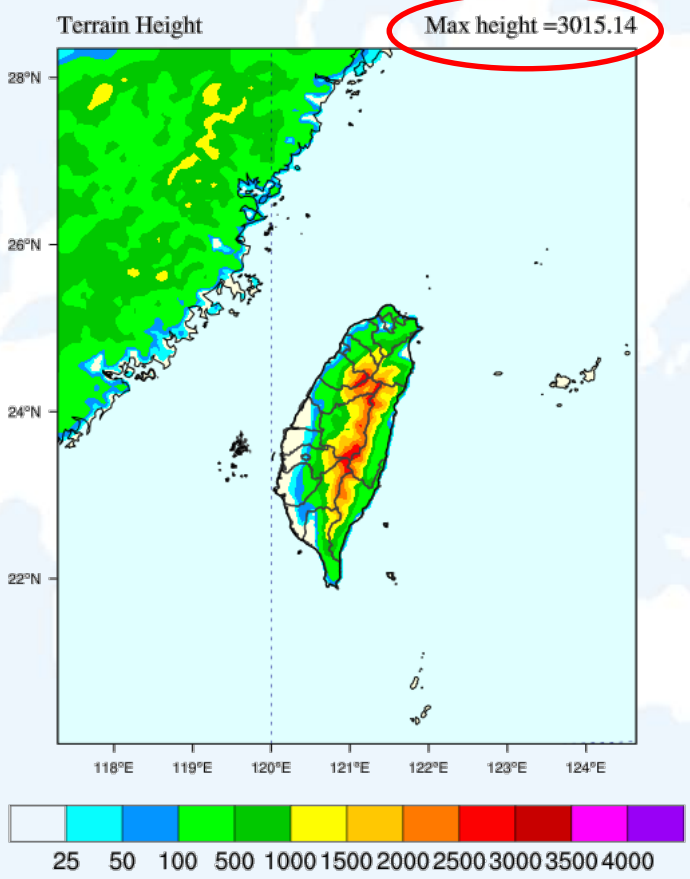

D1: 662*386 (15-km)
D2: 1161*676 (3-km)
52 levels in the vertical

# TWRF Model configurations

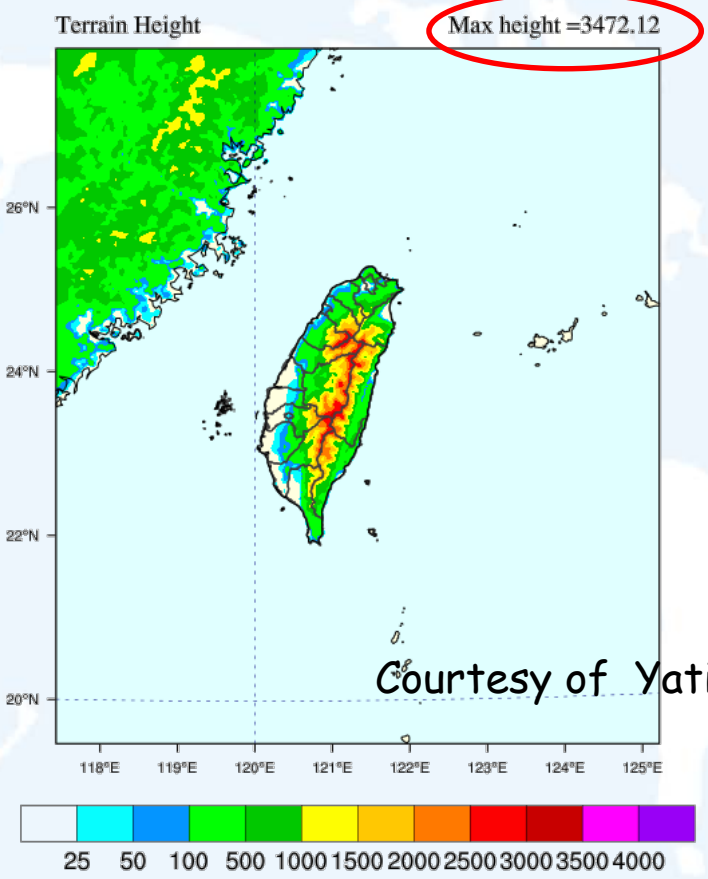
- 4 times per day (00, 06, 12, 18 UTC)
  - 15/3-km resolution, 52 vertical levels
    - Partial cycle, BC from NCEP GFS, CV3 BES

- Model physics
  - **Microphysics: Goddard MPS**
  - **Cumulus: Kain-Fritch scheme with new trigger function**
  - **PBL: YSU scheme**
  - **Surface layer: Monin-Obukhov scheme**
  - **Land process: NOAH**
  - **Long wave and short wave radiation: RRTMG**
  - **Gravity drag parameterization**

## Model terrain height (m) @ 5km




## Model terrain height (m) @ S 3km



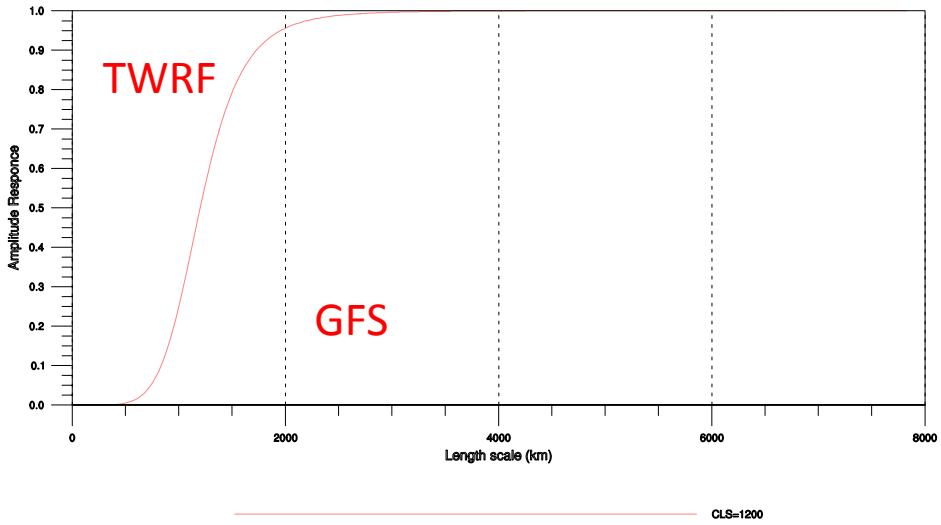

Courtesy of Yating Tsai

# Blending the GFS analysis with TWRF to improve the IC

$$BLD_{ana} = TWRF_{ana} - \overline{TWRF_{ana}}^{RF} + \overline{GFS_{ana}}^{RF}$$

Small scale from TWRF

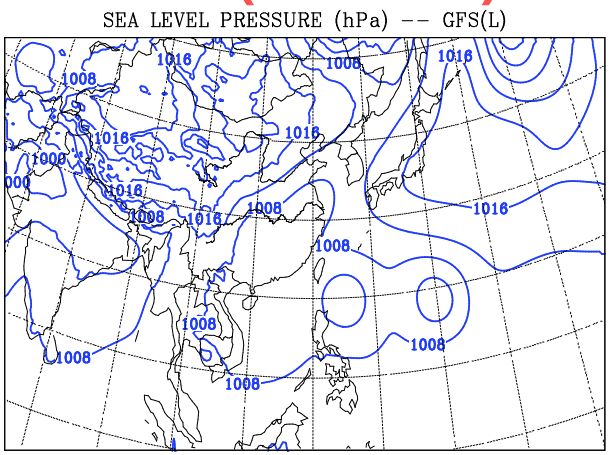
Large scale from GFS




CLS=1200 km

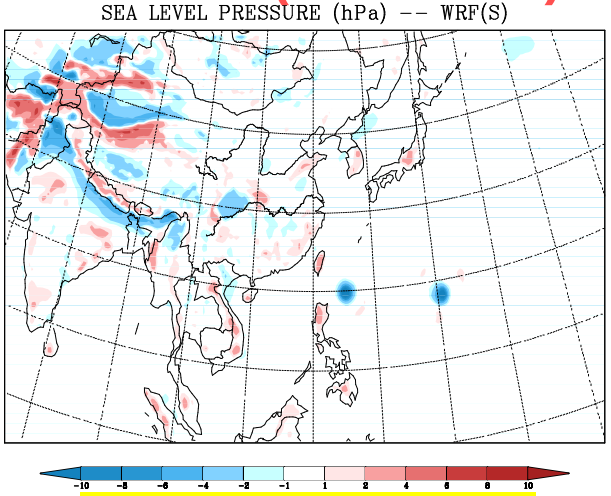
# Case study: TEMBIN (2012082100)

## GFS (>1200km)



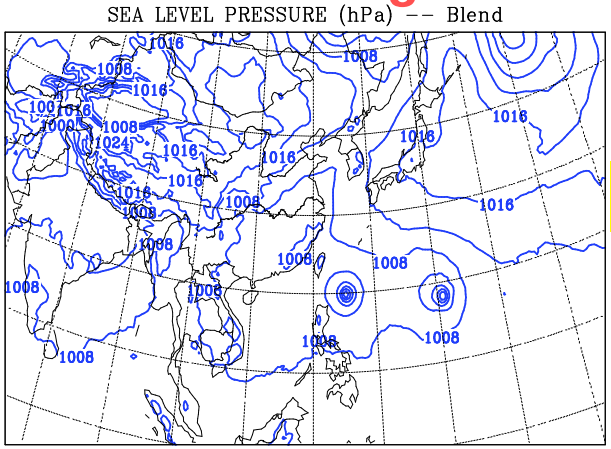

large scale features

## TWRF (difference)




small scale features

## Blending




New initial field

# Cases & DOE of TWRF2.0 (1-Way, 15km)

| | Resolution | Partial cycling | CLS of Blending |
|---|---|---|---|
| TWRF2.0 | 15/3 km, η= 52 | 2 | 1200 km |
| TWRF2.0_300 | 15/3 km, η= 52 | 2 | 300 km |
| TWRF2.0_p1 | 15/3 km, η= 52 | 1 | 1200 km |
| TWRF1.5 | 45/15/5 km, η= 45 | 2 | 1200 km |

| | Date | Intensity | Movement | Cases no. |
|---|---|---|---|---|
| Noul* | 2015/05/03/18~2015/05/09/06 | Strong | Recurved | 23 |
| Chan-Hom* | 2015/07/05/06~2015/07/10/00 | Medium-strength | Recurved | 20 |
| Linfa* | 2015/07/04/00~2015/07/09/06 | Weak | Westward | 22 |
| Nangka | 2015/07/05/18~2015/07/10/00 | Strong | Recurved | 18 |
| Soudelor* | 2015/08/02/12～2015/08/07/12 | Strong | Westward | 21 |
| Goni* | 2015/08/18/00～2015/08/21/00 | Strong | Recurved | 13 |
| Atsani | 2015/08/19/00～2015/08/21/00 | Strong | Recurved | 9 |
| Dujuan* | 2015/09/23/00～2015/09/28/06 | Strong | Westward | 22 |
| KOPPU | 2015/10/14/00～2015/10/16/00 | Strong | Westward | 9 |
| CHAMPI | 2015/10/14/00～2015/10/16/00 | Medium-strength | Recurved | 9 |
| Total cases | | | | 166 |

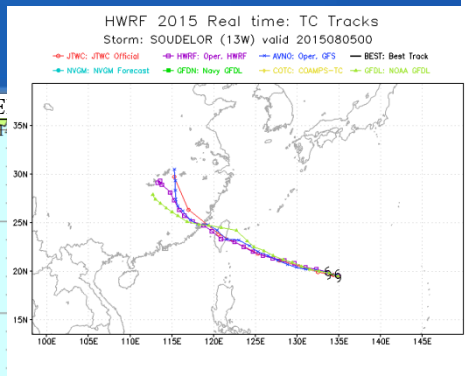
* Warning TC

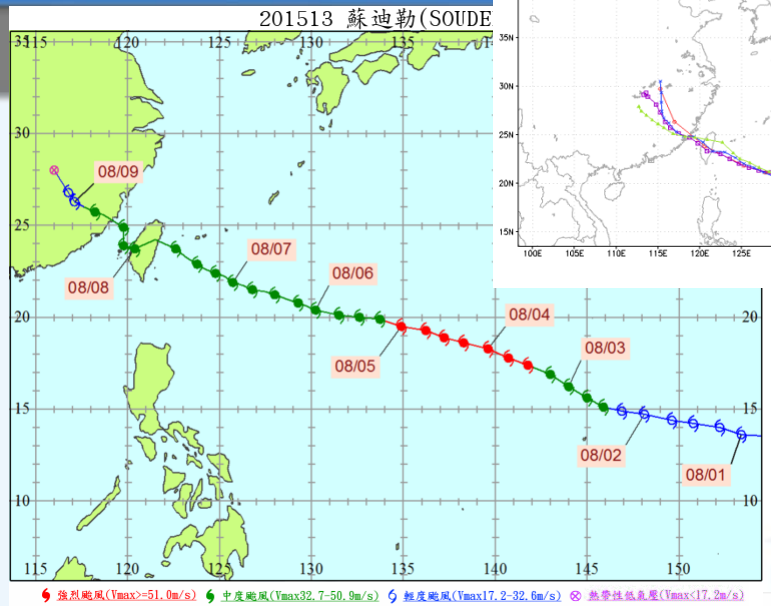
# Cases & DOE of TWRF2.0 (1-Way,3km)

| | Resolution | Partial cycling | CLS of Blending |
|---|---|---|---|
| TWRF2.0 | 15/3 km, η= 52 | 2 | 1200 km |
| TWRF2.0_300 | 15/3 km, η= 52 | 2 | 300 km |
| TWRF2.0_p1 | 15/3 km, η= 52 | 1 | 1200 km |
| TWRF1.5 | 45/15/5 km, η= 45 | 2 | 1200 km |

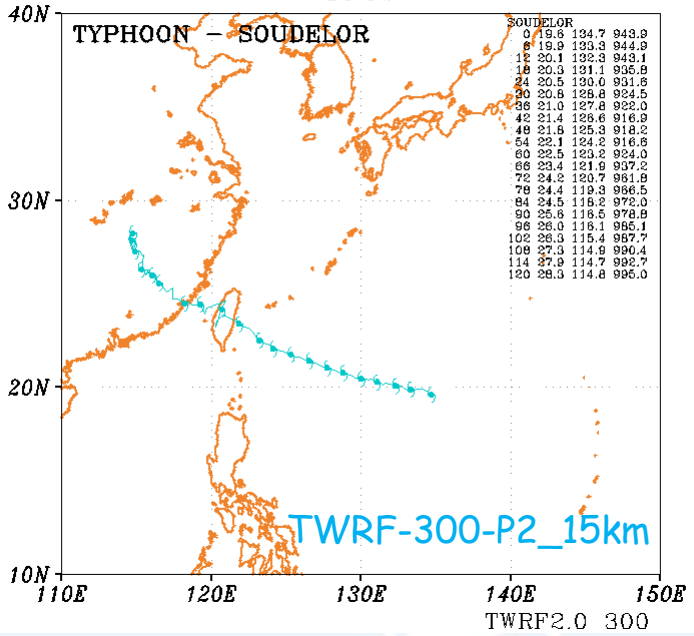
| | Date | Intensity | Movement | Cases no. |
|---|---|---|---|---|
| Noul* | 2015/05/09/06~2015/05/09/06 | Strong | Recurved | 1 |
| Chan-Hom* | 2015/07/07/18~2015/07/10/00 | Medium-strength | Recurved | 10 |
| Linfa* | 2015/07/04/00~2015/07/09/06 | Weak | Westward | 22 |
| Soudelor* | 2015/08/04/12～2015/08/07/12 | Strong | Westward | 13 |
| Goni* | 2015/08/18/00～2015/08/21/00 | Strong | Recurved | 13 |
| Dujuan* | 2015/09/23/00～2015/09/28/06 | Strong | Westward | 22 |
| KOPPU | 2015/10/14/00～2015/10/16/00 | Strong | Westward | 9 |
| Total cases | | | | 90 |

* Warning TC

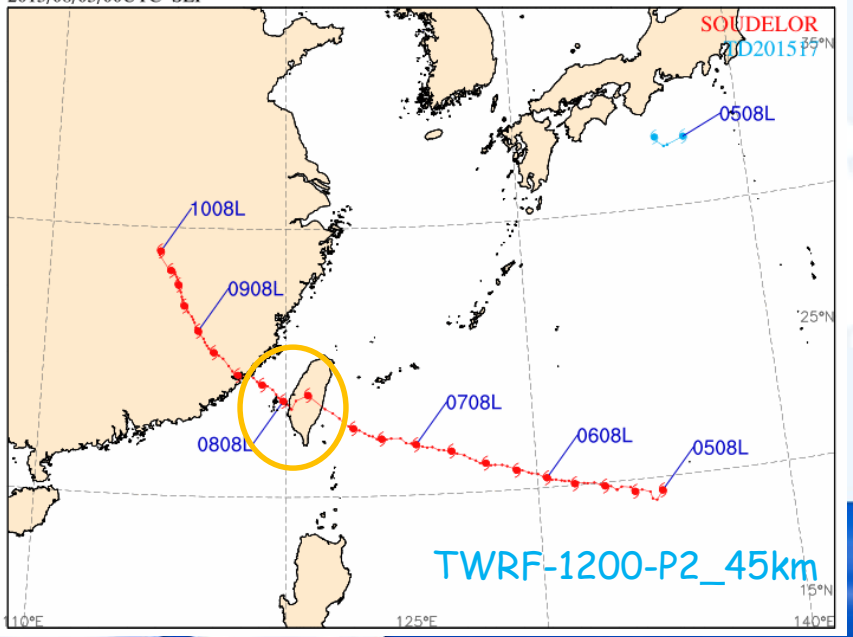


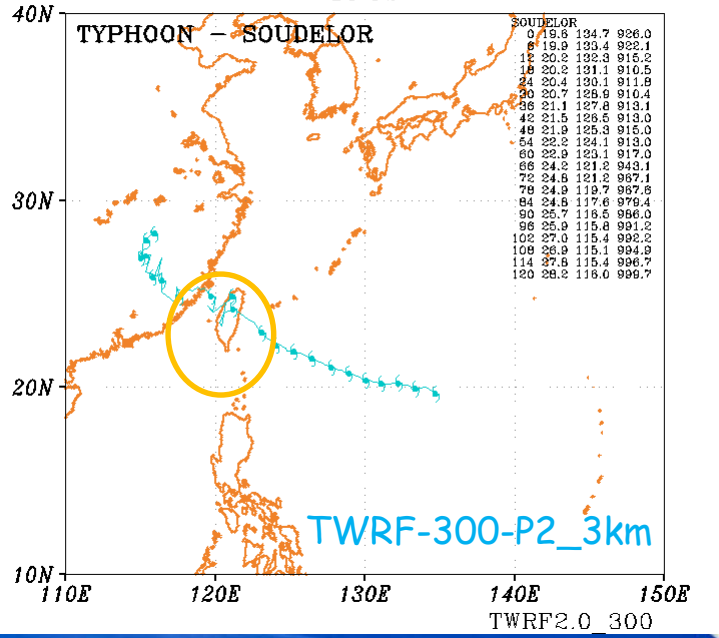

TWRF(15km) TYPHOON TRACK FORECAST(15/08/05/00UTC)
BY PS

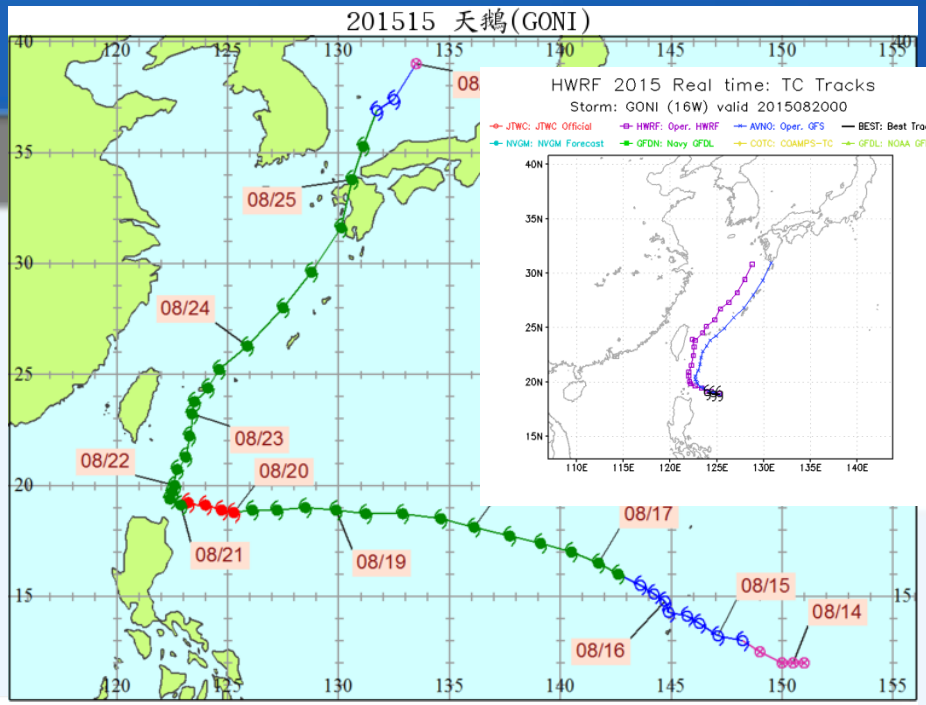


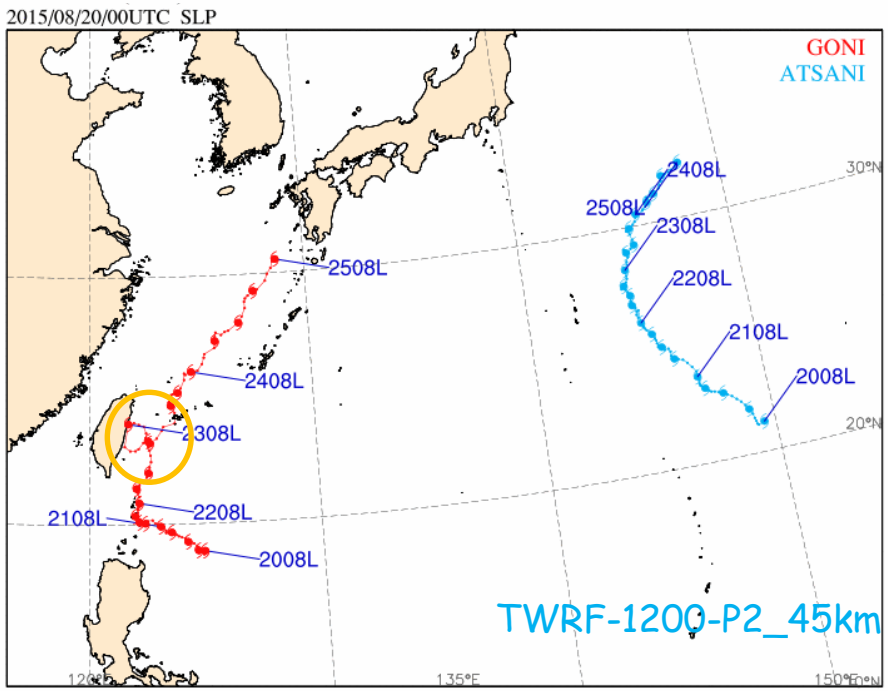

CWB TWRF (15km) TYPHOON TRACK FORECAST
2015/08/05/00UTC SLP

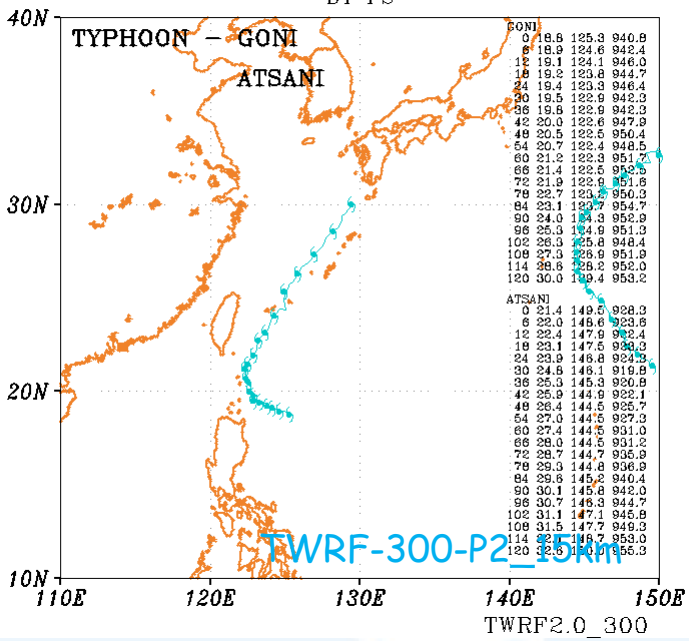


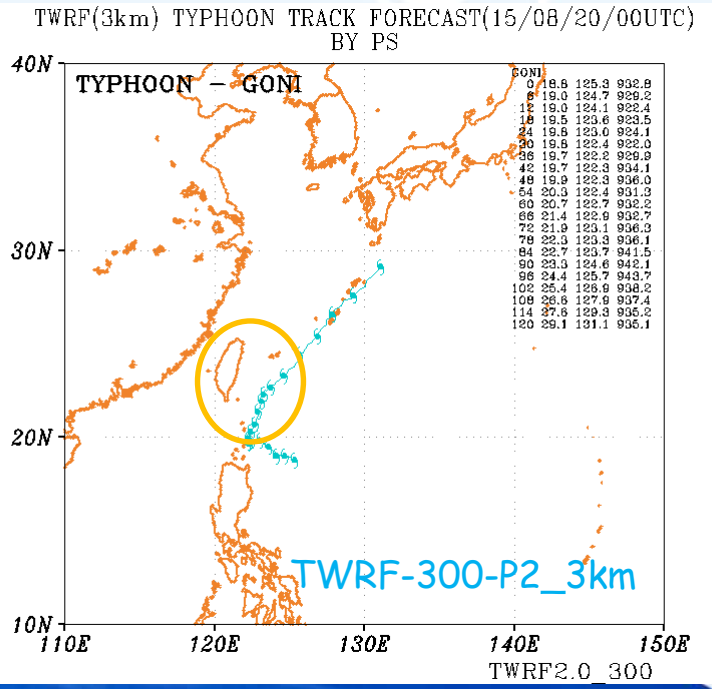

TWRF(3km) TYPHOON TRACK FORECAST(15/08/05/00UTC)
BY PS

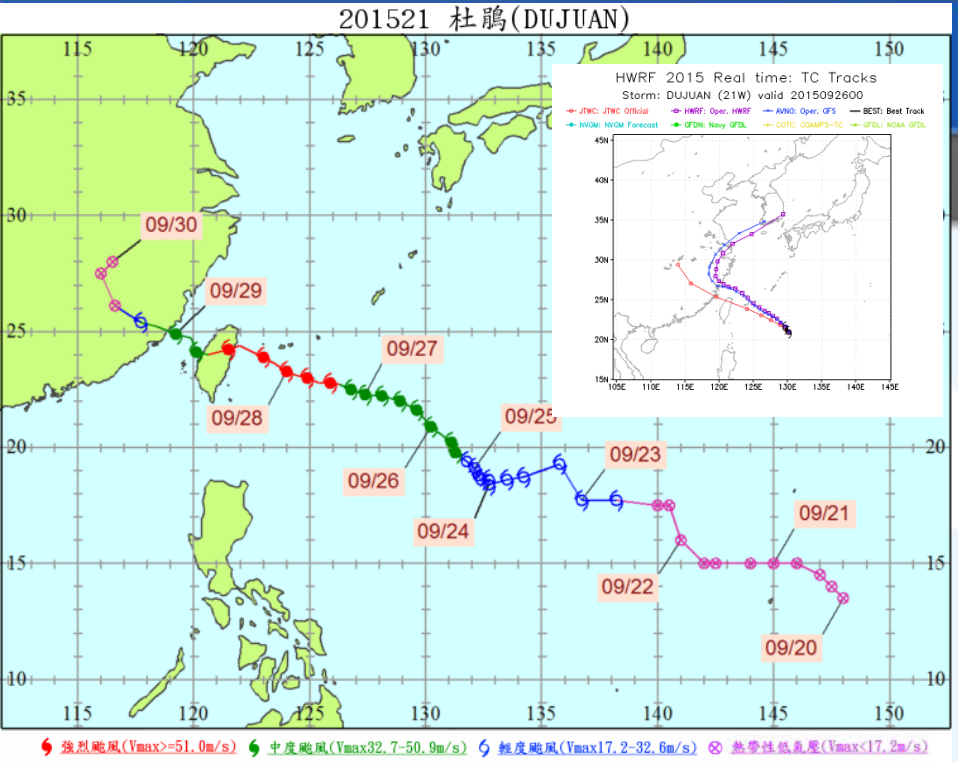


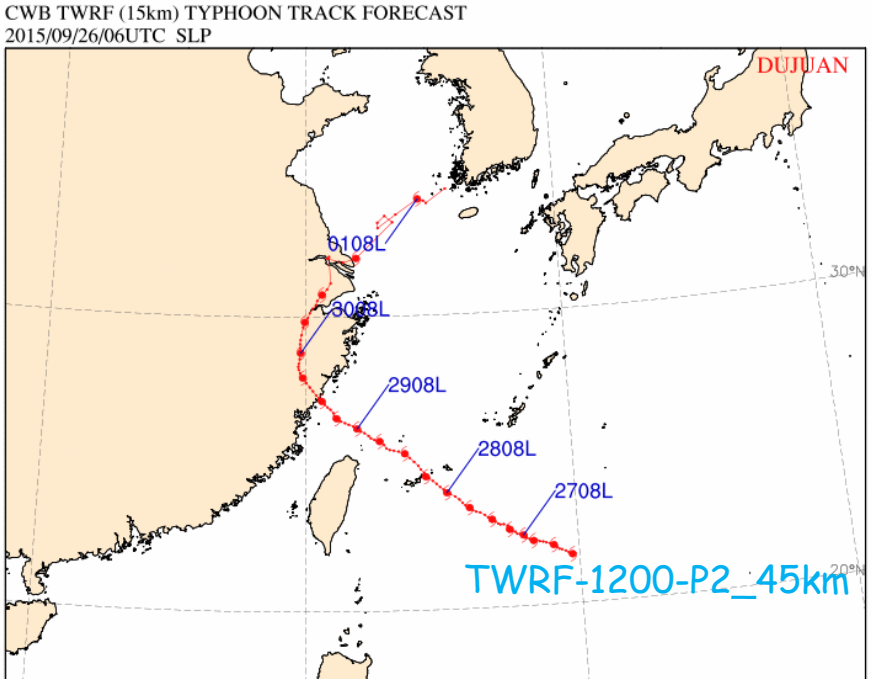

201515 天鹅(GONI)
08/25
08/24
08/23
08/22
08/20
08/21
08/19
08/17
08/15
08/14
08/16
HWRF 2015 Real time: TC Tracks
Storm: GONI (16W) valid 2015082000
JTWC: JTWC Official
HWRF: Oper. HWRF
AVNO: Oper. GFS
BEST: Best Track
NVGM: NVGM Forecast
GFDN: Navy GFDL
COTC: COAMPS-TC
GFDL: NOAA GFDL
強烈颱風(Vmax>=51.0m/s)
中度颱風(Vmax32.7-50.9m/s)
輕度颱風(Vmax17.2-32.6m/s)
熱帶性低氣壓(Vmax<17.2m/s)

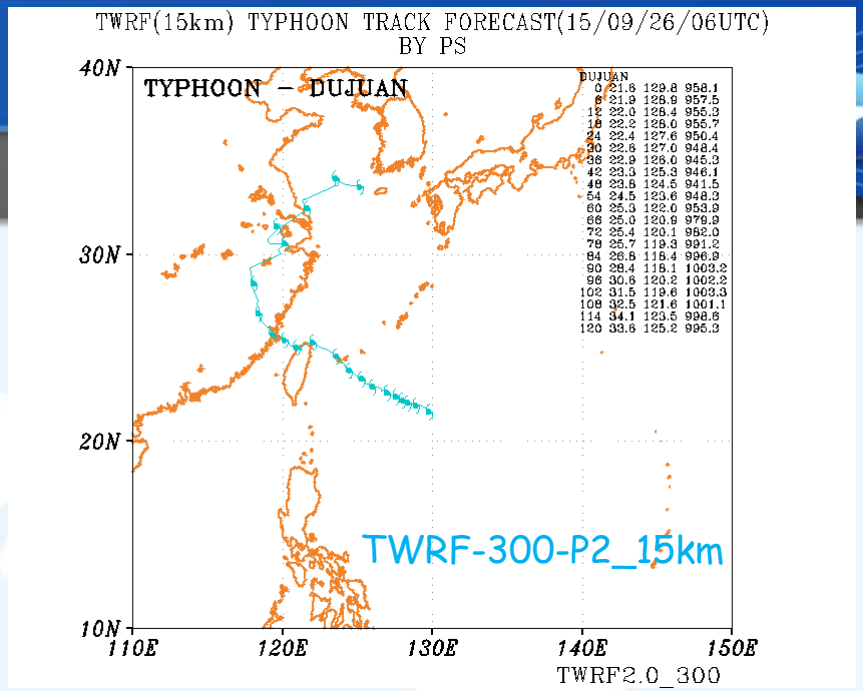

2015/08/20/00UTC SLP
GONI
ATSANI
2408L
2508L
2308L
2208L
2108L
2008L
TWRF-1200-P2_45km

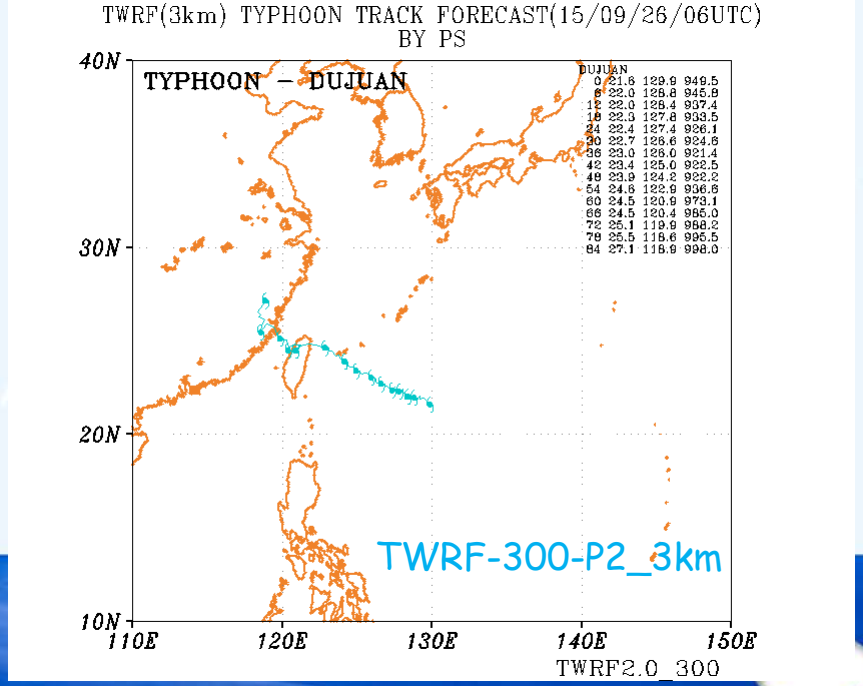

TWRF(15km) TYPHOON TRACK FORECAST(15/08/20/00UTC)
BY PS
TYPHOON – GONI
ATSANI
TWRF-300-P2_15km
TWRF2.0_300

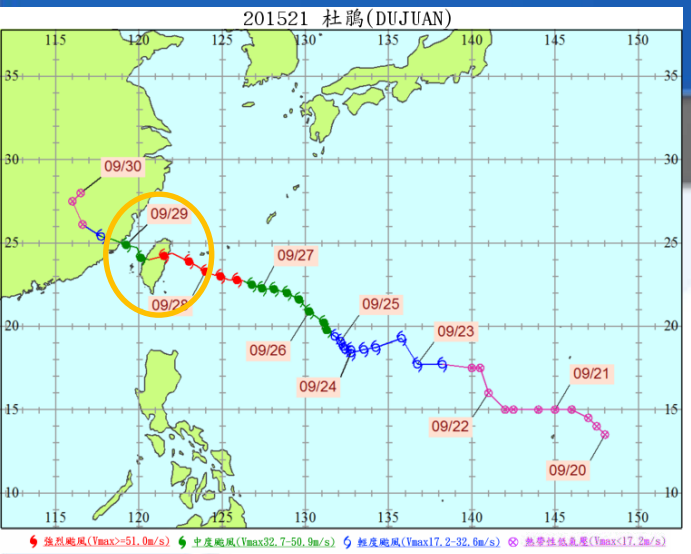

TWRF(3km) TYPHOON TRACK FORECAST(15/08/20/00UTC)
BY PS
TYPHOON – GONI
TWRF-300-P2_3km
TWRF2.0_300

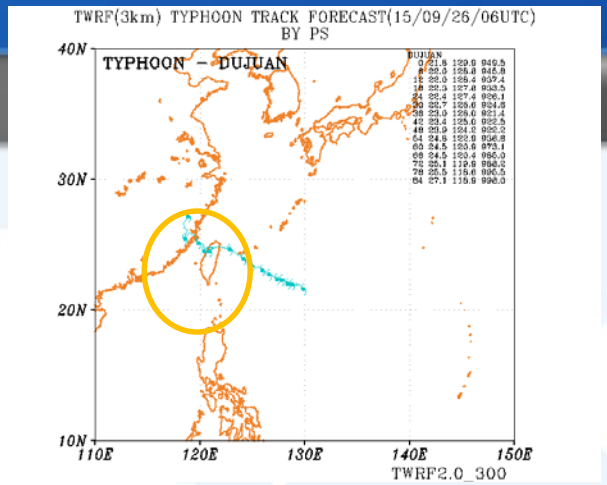

201521 杜鵑(DUJUAN)
HWRF 2015 Real time: TC Tracks
Storm: DUJUAN (21W) valid 2015092600
09/30
09/29
09/28
09/27
09/26
09/25
09/24
09/23
09/22
09/21
09/20
強烈颱風(Vmax>=51.0m/s)
中度颱風(Vmax32.7-50.9m/s)
輕度颱風(Vmax17.2-32.6m/s)
熱帶性低氣壓(Vmax<17.2m/s)

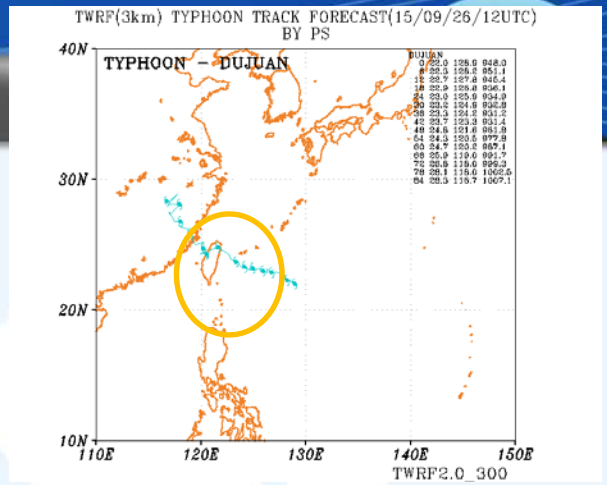

CWB TWRF (15km) TYPHOON TRACK FORECAST
2015/09/26/06UTC SLP
DUJUAN
0108L
3008L
2908L
2808L
2708L
TWRF-1200-P2_45km


TWRF(15km) TYPHOON TRACK FORECAST(15/09/26/06UTC)
BY PS
TYPHOON – DUJUAN
TWRF-300-P2_15km
TWRF2.0_300


TWRF(3km) TYPHOON TRACK FORECAST(15/09/26/06UTC)
BY PS
TYPHOON – DUJUAN
TWRF-300-P2_3km
TWRF2.0_300

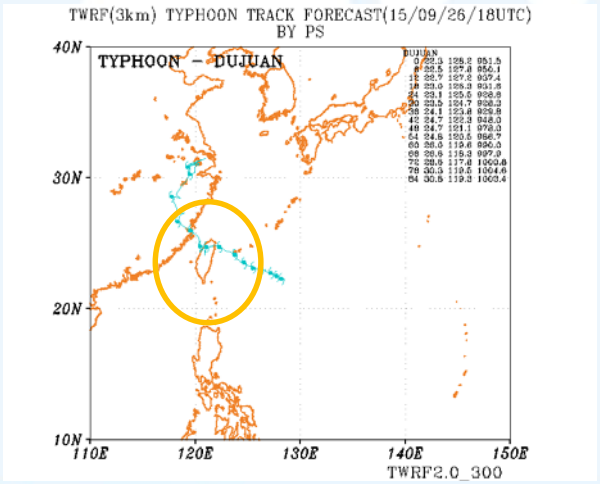


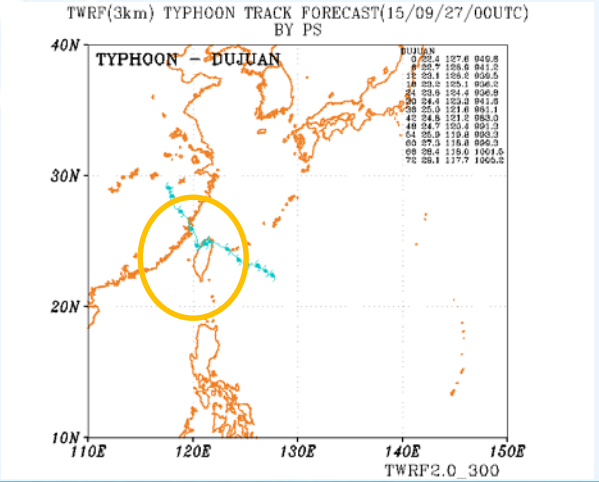



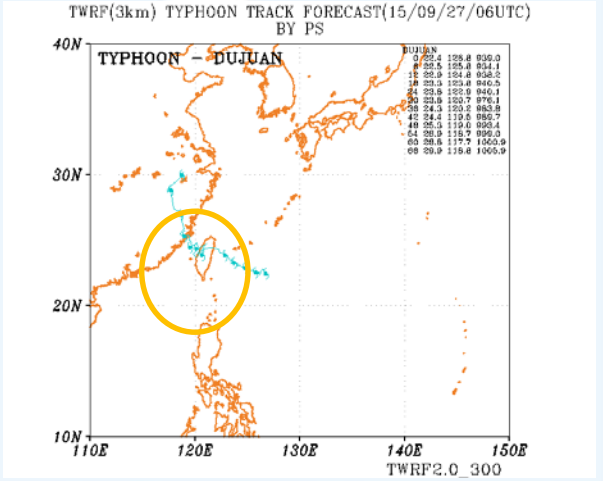




# Topography effect on TC track

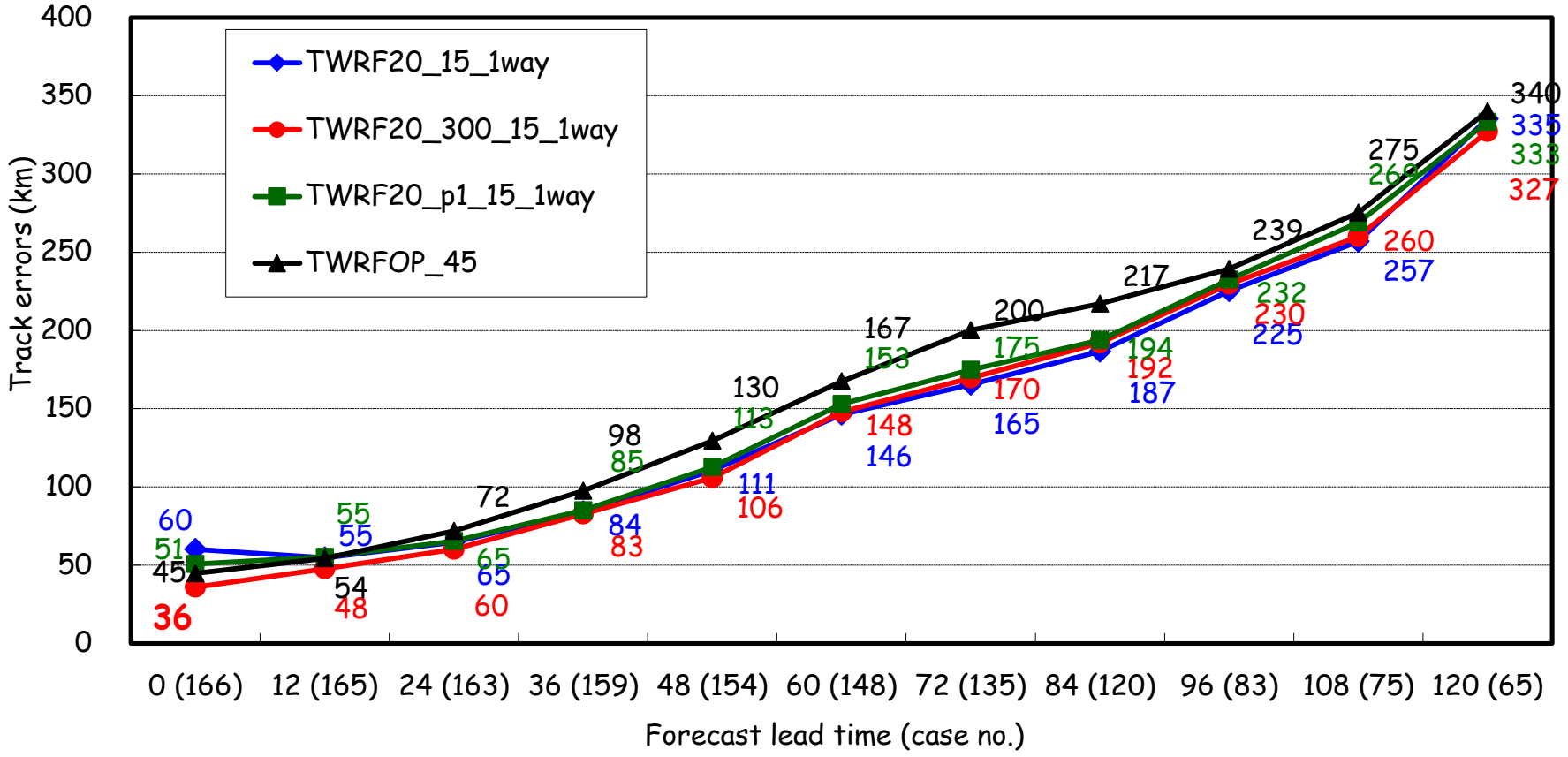
TWRF-300-P2_3km



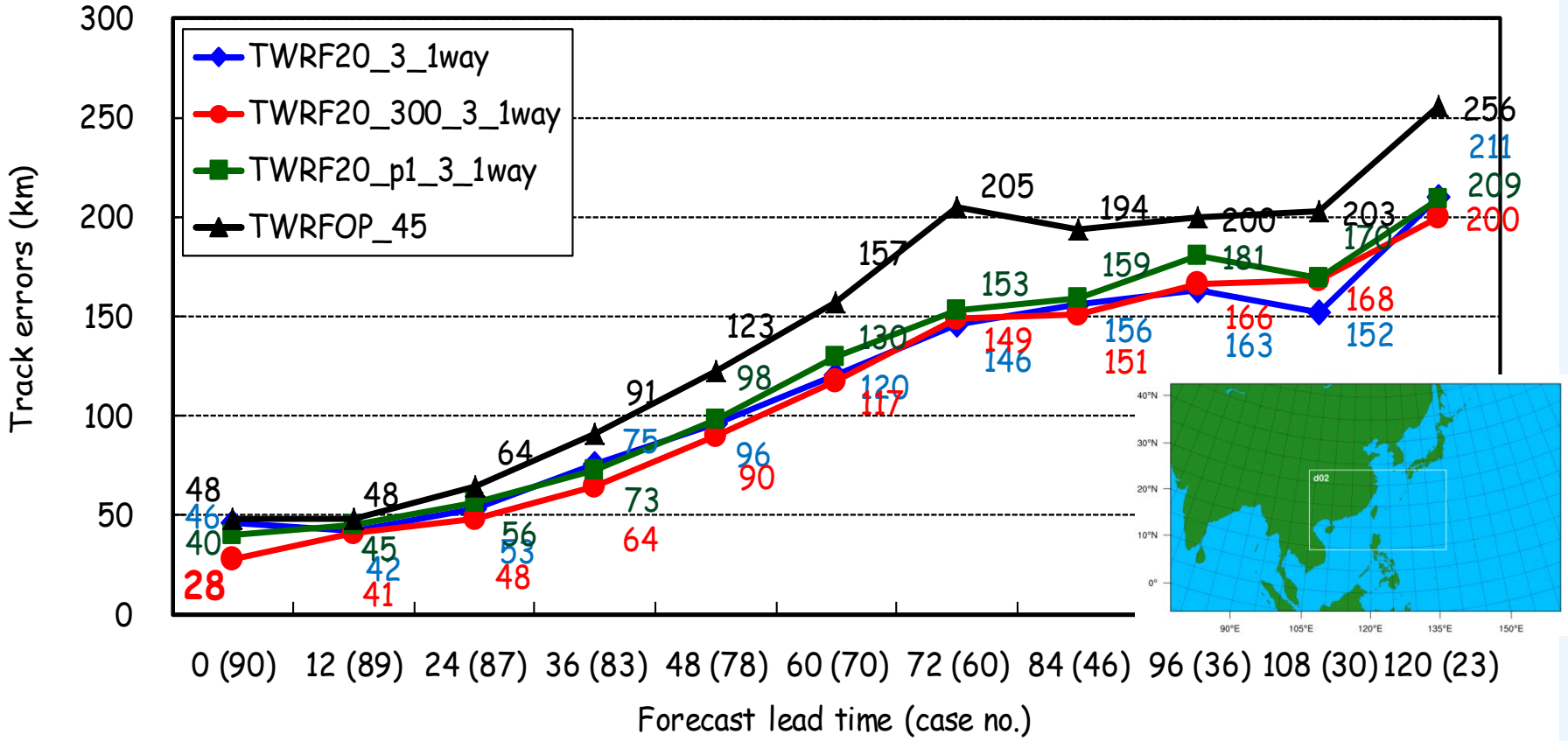



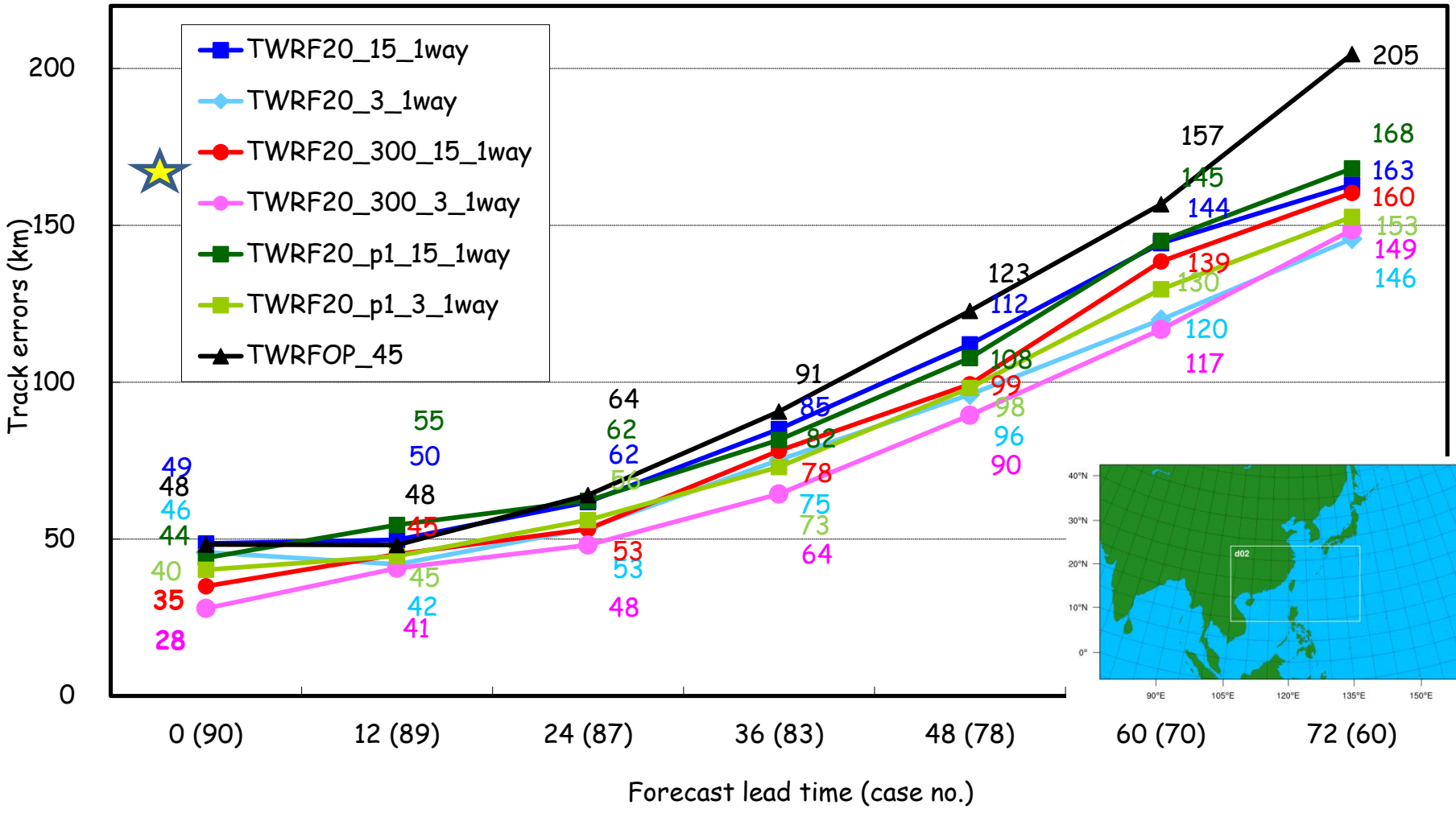
# Experiments result for TWRF2.0(15km) to 2015
# 10 TCs 166 cases



# Experiments result for TWRF2.0(3km) to 2015
# 7 TCs 90 cases

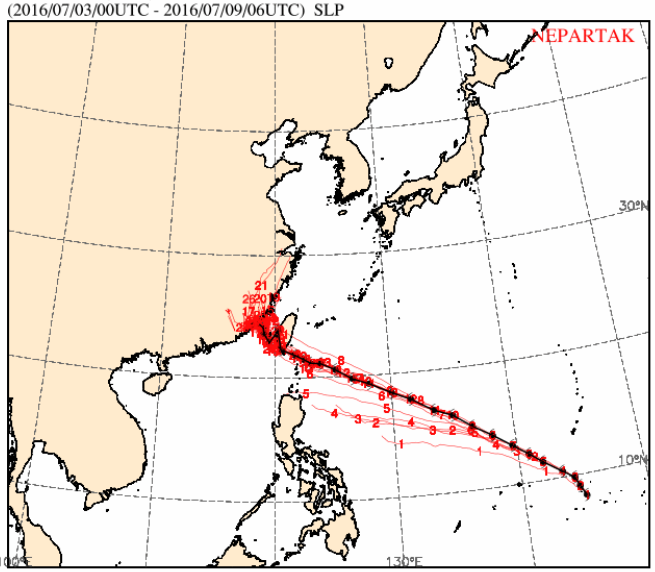


# Experiments result for TWRF2.0 (15km V.S. 3km) to 2015
## 7 TCs 90 cases

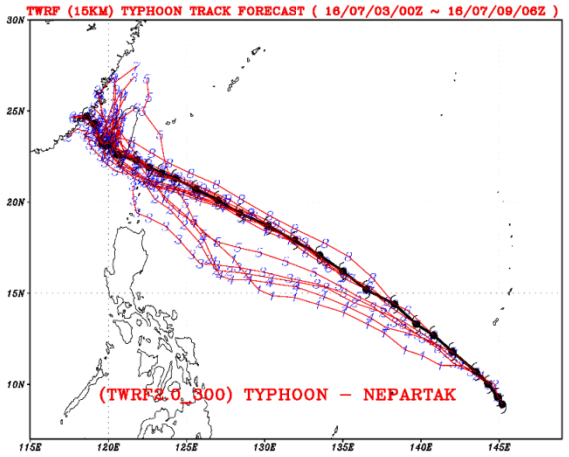


# Nepartak

CWB TWRF (45km) TYPHOON TRACK FORECAST
(2016/07/03/00UTC - 2016/07/09/06UTC) SLP



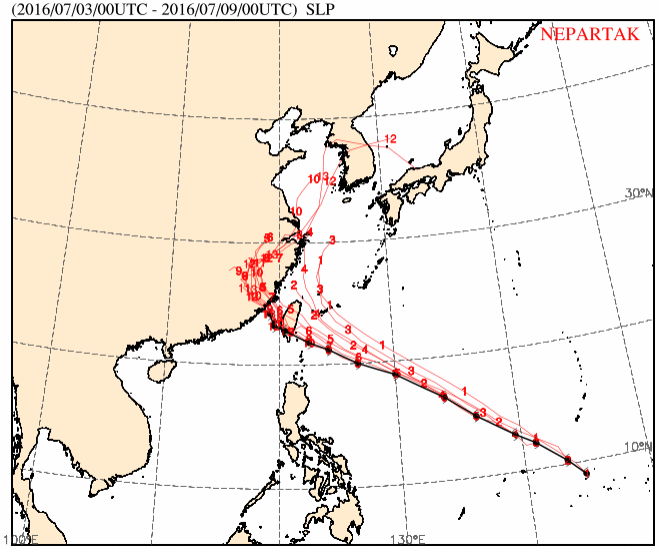

TWRF1.5




TWRF2.0

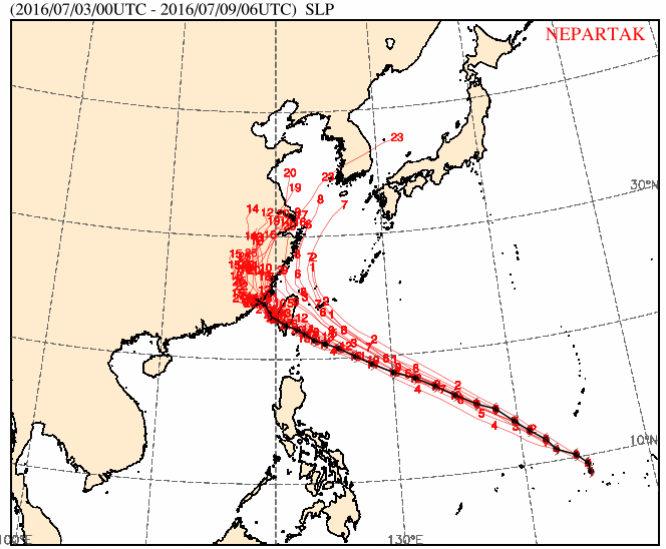
ECMWF

ECMWF TYPHOON TRACK FORECAST
(2016/07/03/00UTC - 2016/07/09/00UTC) SLP

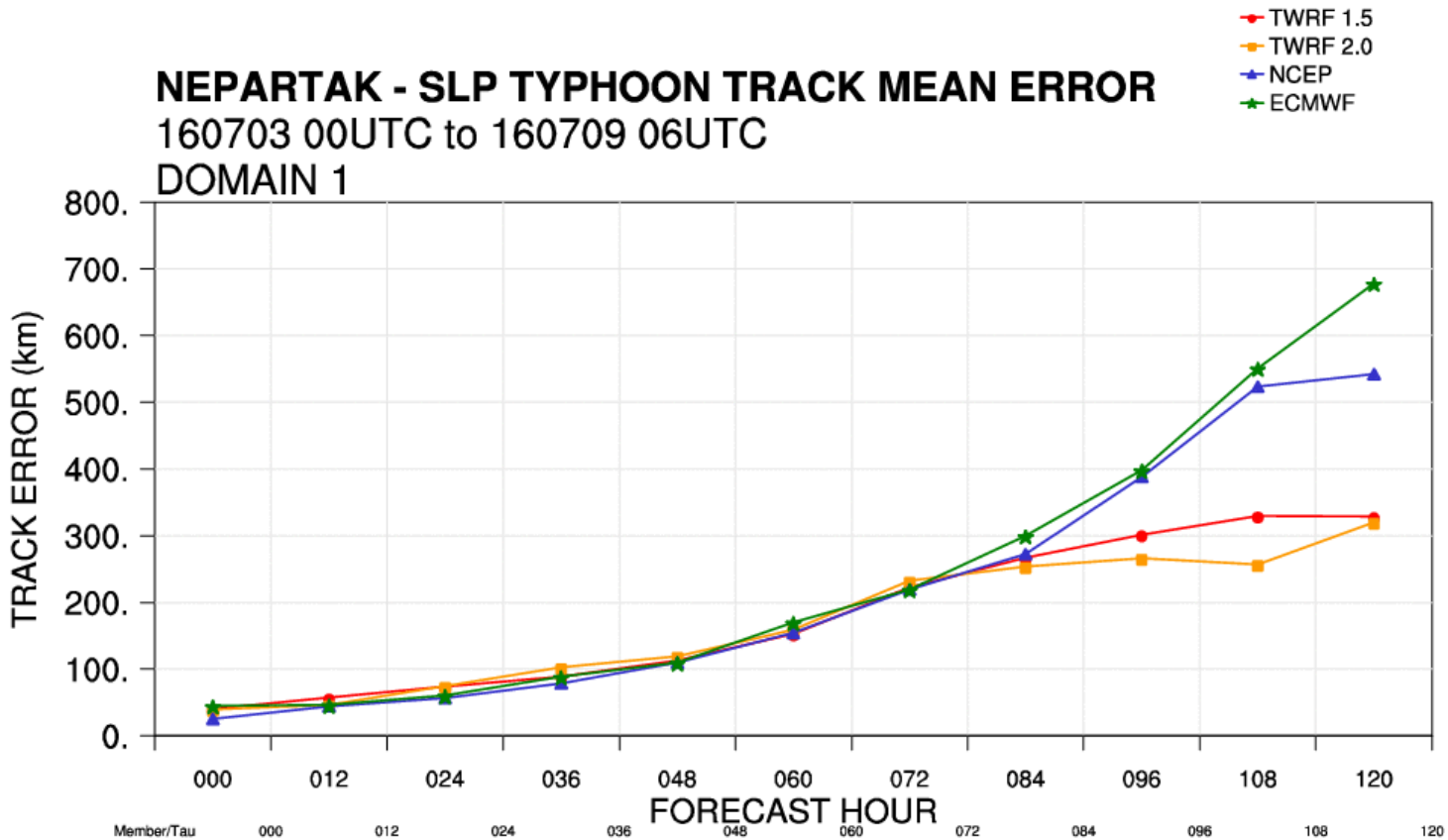



NCEP

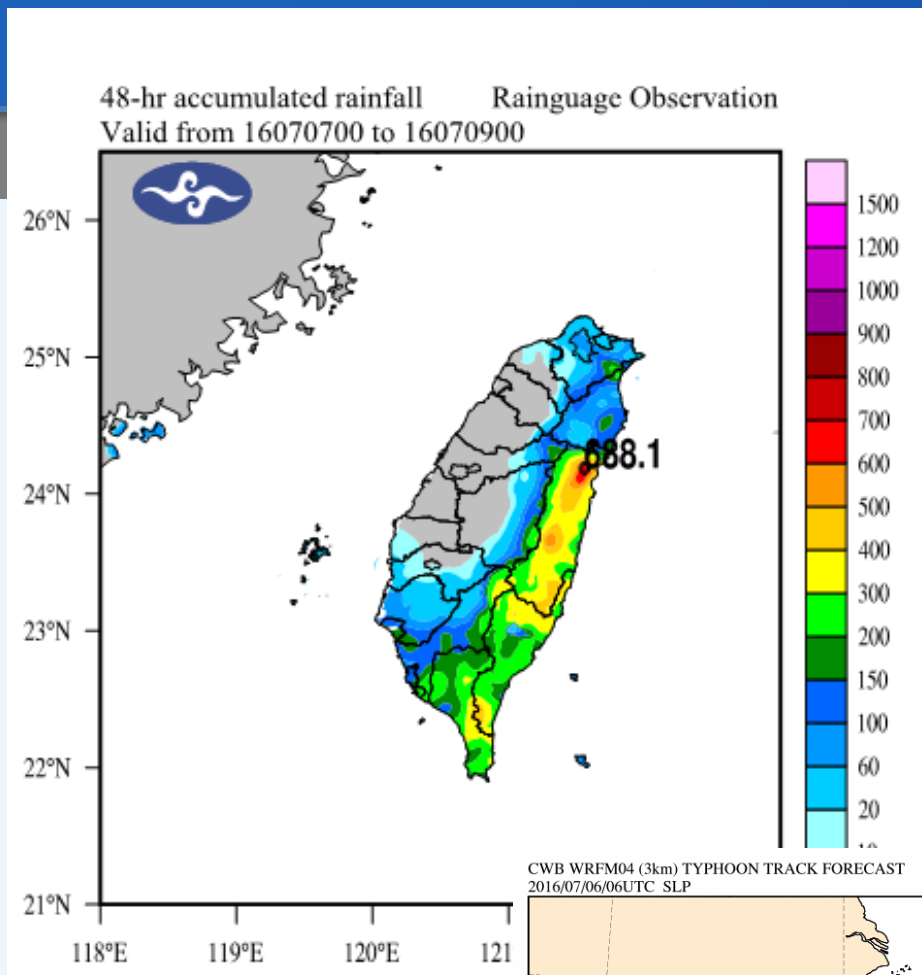
NCEP TYPHOON TRACK FORECAST
(2016/07/03/00UTC - 2016/07/09/06UTC) SLP

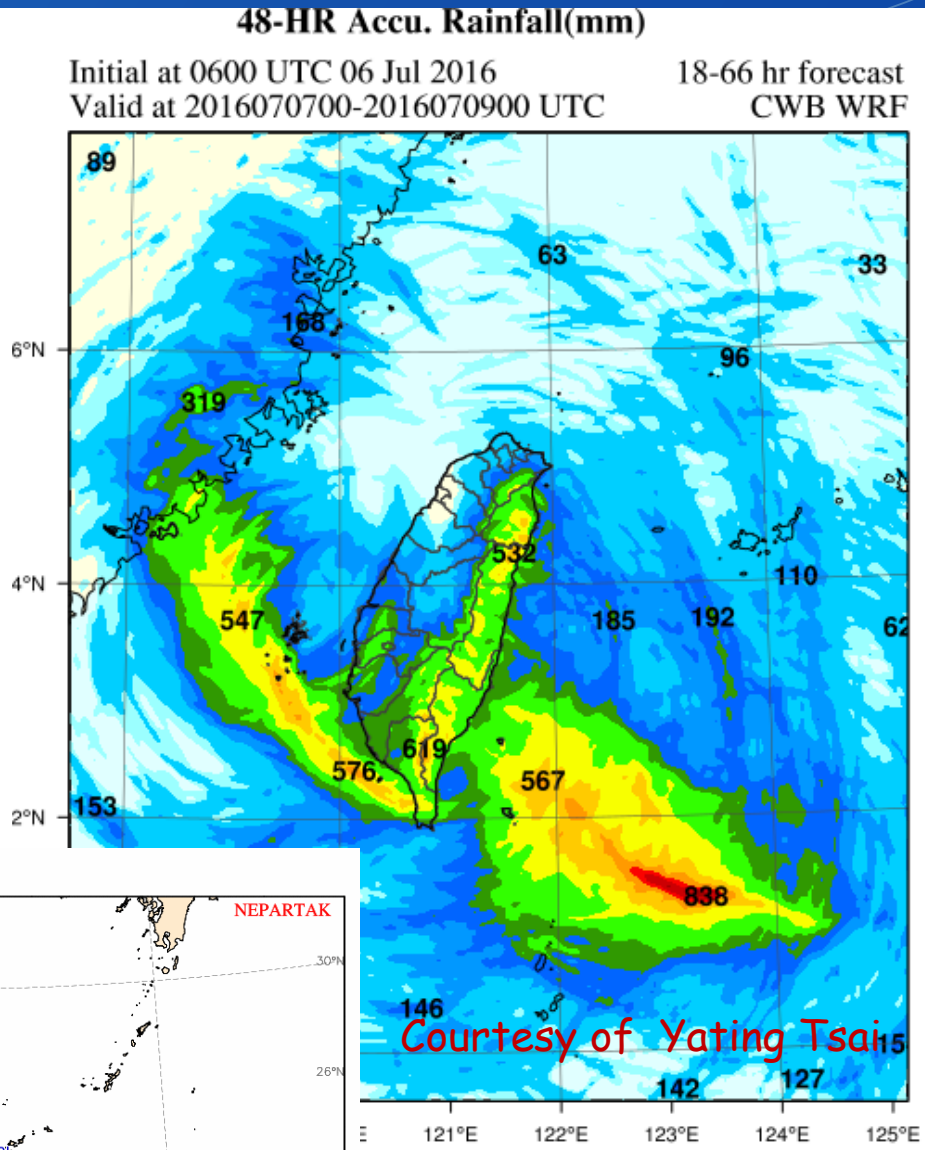


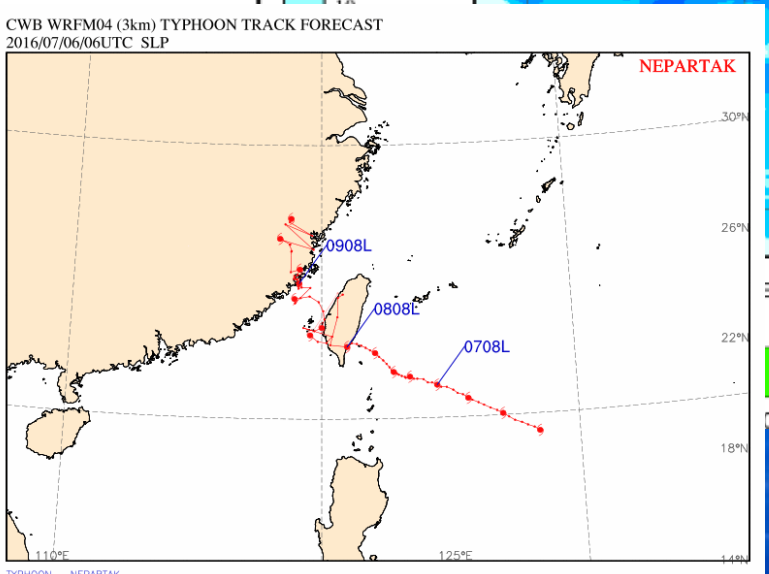
# Nepartak




| Member/Tau | 000 | 012 | 024 | 036 | 048 | 060 | 072 | 084 | 096 | 108 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TWRF 1.5 | 40.0( 26) | 57.2( 24) | 73.6( 22) | 89.0( 20) | 113.1( 18) | 153.0( 16) | 222.3( 14) | 266.9( 12) | 301.7( 10) | 329.9( 8) | 328.9( 6) |
| TWRF 2.0 | 39.7( 26) | 46.7( 24) | 74.4( 22) | 102.6( 20) | 119.4( 18) | 159.1( 16) | 232.3( 14) | 254.0( 12) | 266.5( 10) | 257.2( 8) | 320.4( 6) |
| NCEP | 25.2( 23) | 44.3( 21) | 56.6( 19) | 78.8( 17) | 110.0( 17) | 154.1( 16) | 219.0( 14) | 272.7( 12) | 387.9( 10) | 523.2( 8) | 542.3( 6) |
| ECMWF | 45.0( 12) | 46.2( 11) | 60.2( 10) | 88.9( 9) | 109.6( 9) | 170.1( 8) | 219.6( 7) | 300.0( 6) | 398.2( 5) | 551.2( 4) | 678.6( 3) |

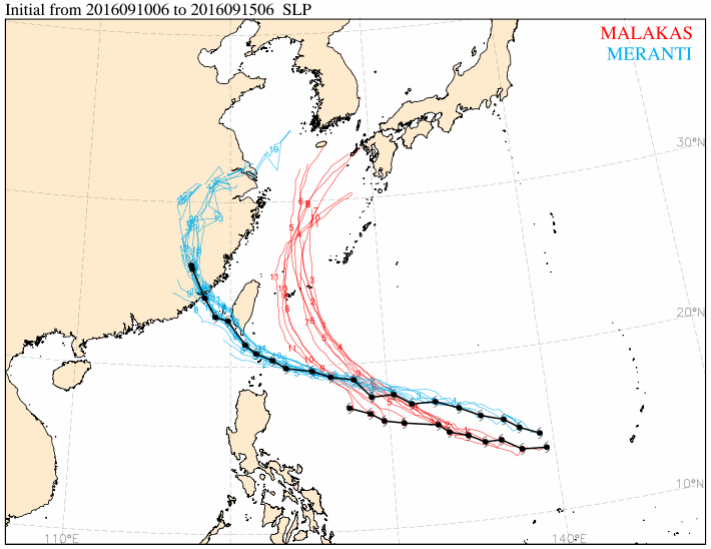

48-hr accumulated rainfall Rainguage Observation
Valid from 16070700 to 16070900
688.1
26°N
25°N
24°N
23°N
22°N
21°N
118°E
119°E
120°E
121
1500
1200
1000
900
800
700
600
500
400
300
200
150
100
60
20


48-HR Accu. Rainfall(mm)
Initial at 0600 UTC 06 Jul 2016
Valid at 2016070700-2016070900 UTC
18-66 hr forecast
CWB WRF
89
63
33
168
96
319
6°N
532
110
547
185
192
4°N
619
576
567
153
838
146
142
127
15
121°E
122°E
123°E
124°E
125°E
0
300
400
500
600
700
800
900
1000
1200
1500
Courtesy of Yating Tsai


CWB WRFM04 (3km) TYPHOON TRACK FORECAST
2016/07/06/06UTC SLP
NEPARTAK
0908L
0808L
0708L
30°N
26°N
22°N
18°N
110°E
125°E

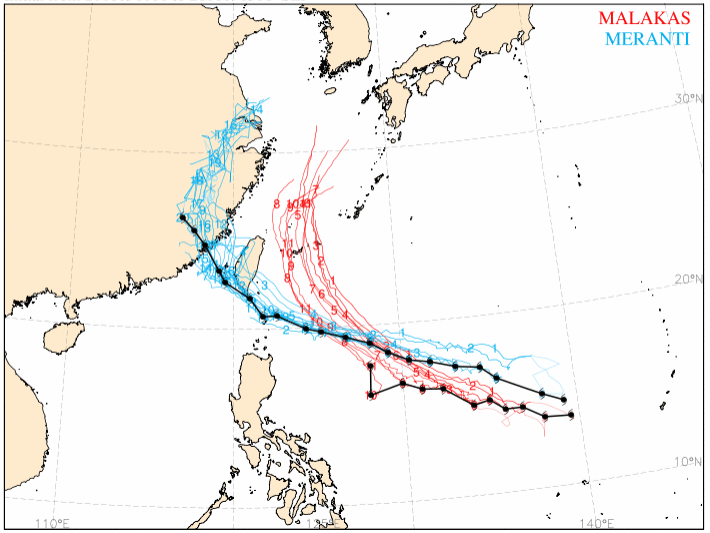
# Meranti

CWB/TWRF1.5 (15km) Typhoon Track Forecast
Initial from 2016091006 to 2016091506 SLP



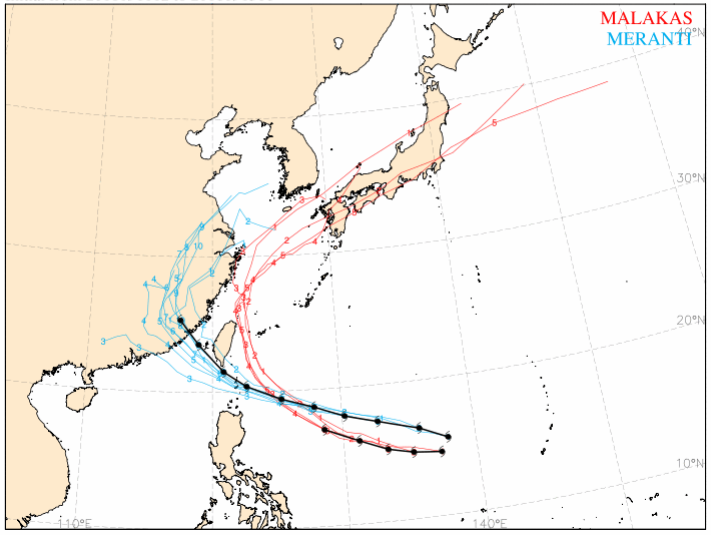

TWRF1.5

CWB/TWRF (3km) Typhoon Track Forecast
Initial from 2016091006 to 2016091506 SLP



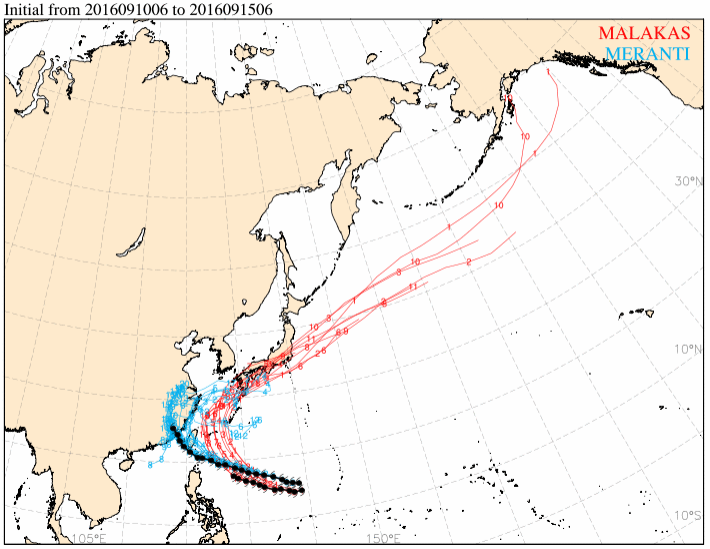

TWRF2.0

ECMWF/IFS Typhoon Track Forecast
Initial from 2016091012 to 2016091500



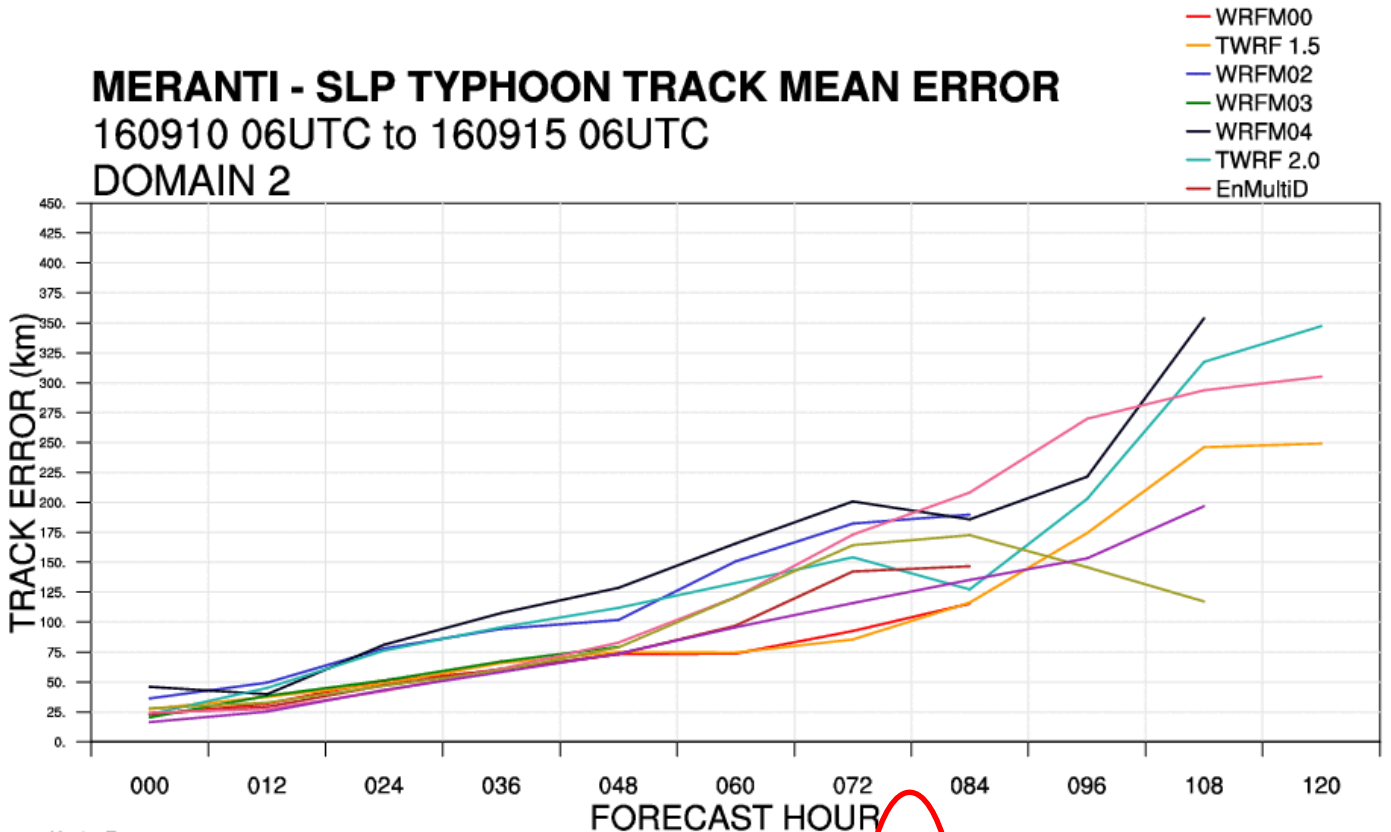

ECMWF

NCEP/GFS Typhoon Track Forecast
Initial from 2016091006 to 2016091506




NCEP

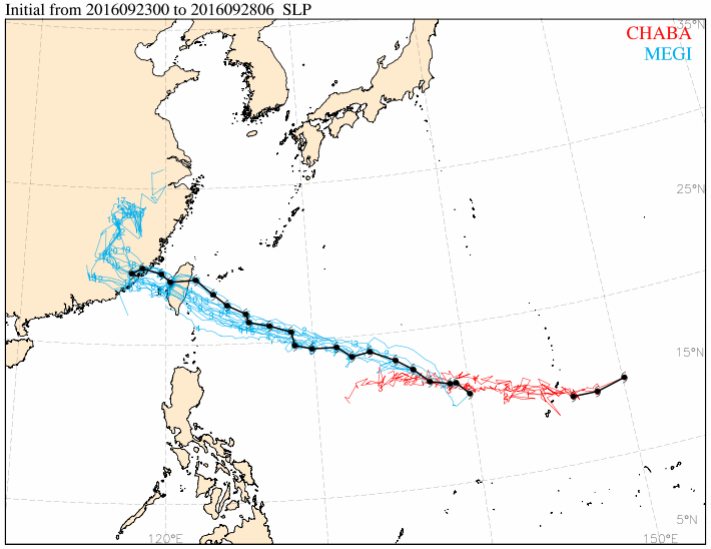
# Meranti




| Member/Tau | 000 | 012 | 024 | 036 | 048 | 060 | 072 | 084 | 096 | 108 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WRFM00 | 22.7( 21) | 31.6( 19) | 51.0( 17) | 59.4( 15) | 73.4( 13) | 73.8( 11) | 92.4( 9) | 115.6( 7) | -999.0( 0) | -999.0( 0) | -999.0( 0) |
| TWRF 1.5 | 27.3( 21) | 37.6( 19) | 48.6( 17) | 65.8( 15) | 75.1( 13) | 74.6( 11) | 85.7( 9) | 116.3( 7) | 174.4( 5) | 246.0( 3) | 249.1( 1) |
| WRFM02 | 36.4( 21) | 49.6( 19) | 77.9( 17) | 94.2( 15) | 101.8( 13) | 150.8( 11) | 182.5( 9) | 189.8( 7) | -999.0( 0) | -999.0( 0) | -999.0( 0) |
| WRFM03 | 20.5( 18) | 38.4( 16) | 51.3( 14) | 67.2( 12) | 79.2( 10) | -999.0( 0) | -999.0( 0) | -999.0( 0) | -999.0( 0) | -999.0( 0) | -999.0( 0) |
| WRFM04 | 46.1( 20) | 39.9( 18) | 81.3( 16) | 107.7( 14) | 128.7( 12) | 165.7( 10) | 200.7( 8) | 185.6( 6) | 221.4( 1) | 353.7( 1) | -999.0( 0) |
| TWRF 2.0 | 23.1( 21) | 44.8( 19) | 76.5( 17) | 95.6( 15) | 112.0( 13) | 132.7( 11) | 154.0( 9) | 127.4( 7) | 202.9( 5) | 317.2( 3) | 347.4( 1) |
| EnMultiD | 23.7( 20) | 29.1( 18) | 47.2( 16) | 60.8( 14) | 73.3( 12) | 96.9( 10) | 142.3( 8) | 146.5( 6) | -999.0( 0) | -999.0( 0) | -999.0( 0) |
| NCEP | 24.5( 20) | 27.5( 19) | 42.4( 17) | 60.9( 15) | 83.0( 13) | 120.7( 11) | 173.1( 9) | 208.1( 7) | 269.8( 5) | 293.5( 3) | 304.9( 1) |
| ECMWF | 27.7( 10) | 32.9( 9) | 46.7( 8) | 59.6( 7) | 79.0( 6) | 120.7( 5) | 164.1( 4) | 172.4( 3) | 145.6( 2) | 117.0( 1) | -999.0( 0) |
| WEPS | 16.5( 20) | 25.1( 18) | 43.1( 16) | 58.4( 14) | 73.7( 12) | 95.5( 10) | 116.0( 8) | 135.4( 6) | 153.4( 4) | 197.0( 2) | -999.0( 0) |

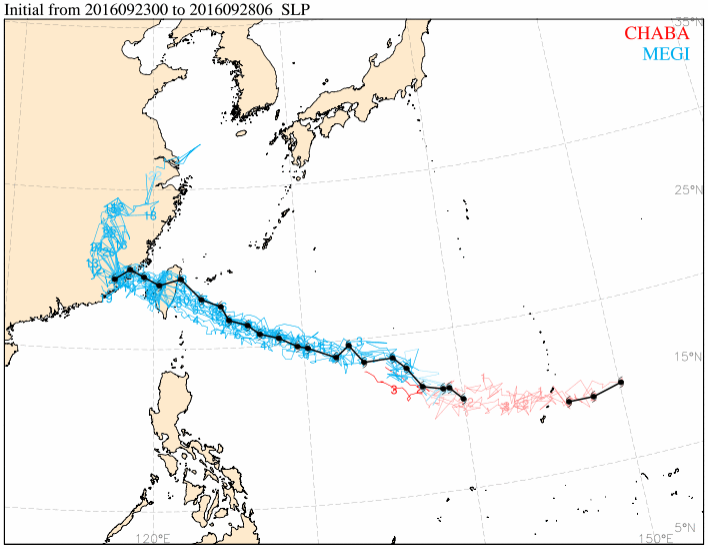
# Megi

CWB/TWRF1.5 (15km) Typhoon Track Forecast
Initial from 2016092300 to 2016092806 SLP



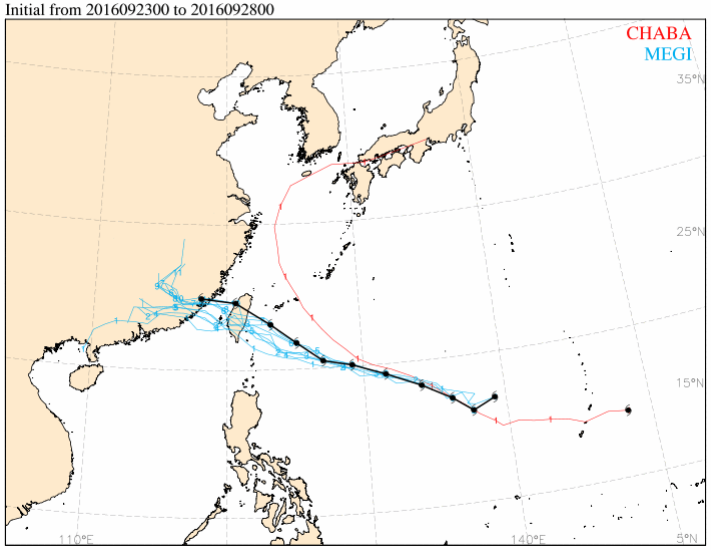

TWRF1.5

CWB/TWRF (3km) Typhoon Track Forecast
Initial from 2016092300 to 2016092806 SLP



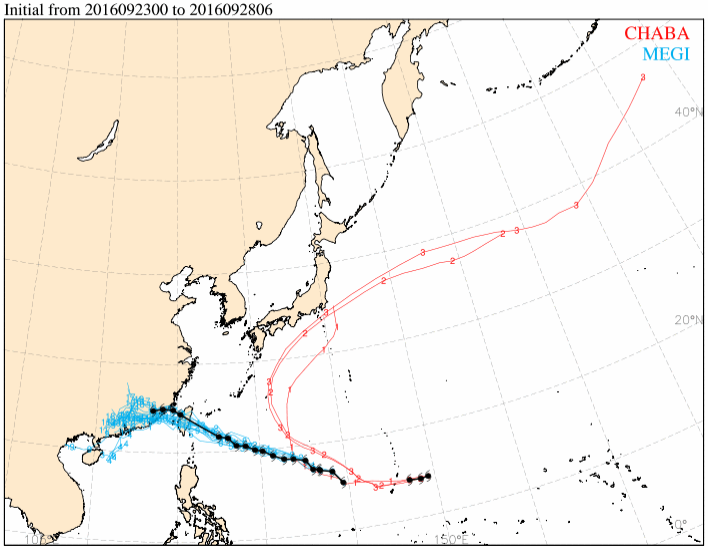

TWRF2.0

ECMWF/IFS Typhoon Track Forecast
Initial from 2016092300 to 2016092800



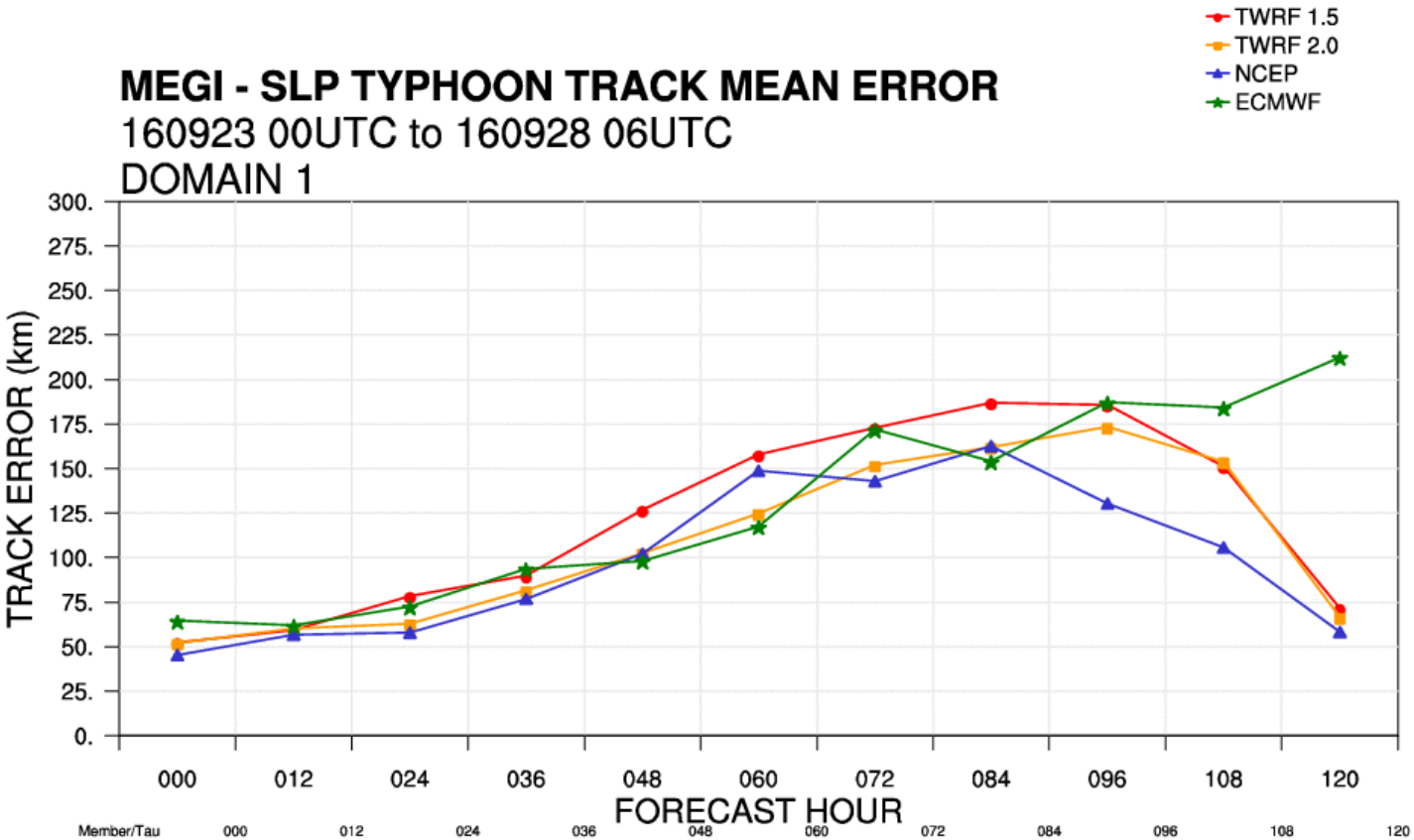

ECMWF

NCEP/GFS Typhoon Track Forecast
Initial from 2016092300 to 2016092806

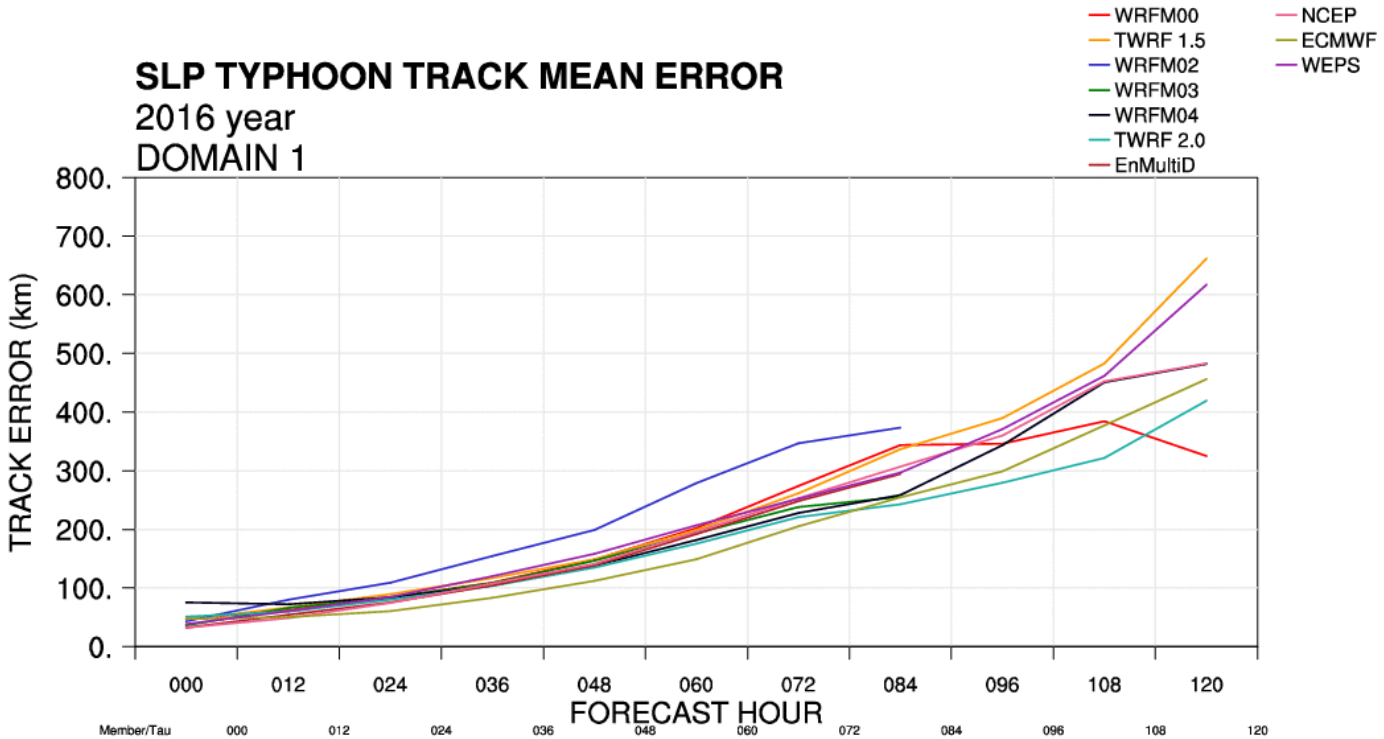



NCEP

# Megi



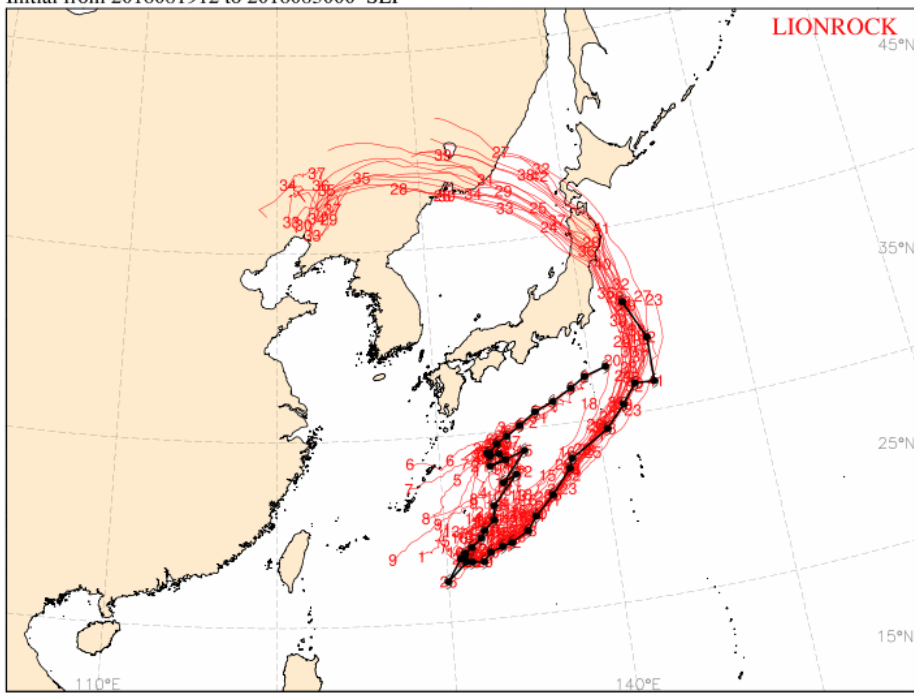

| Member/Tau | 000 | 012 | 024 | 036 | 048 | 060 | 072 | 084 | 096 | 108 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TWRF 1.5 | 52.4( 22) | 59.4( 20) | 78.3( 18) | 89.7( 16) | 126.7( 14) | 157.8( 12) | 173.0( 10) | 187.0( 8) | 185.8( 6) | 151.1( 4) | 71.5( 2) |
| TWRF 2.0 | 52.0( 22) | 60.1( 20) | 62.9( 18) | 81.6( 16) | 102.5( 14) | 124.8( 12) | 152.0( 10) | 162.1( 8) | 173.3( 6) | 153.8( 4) | 66.5( 2) |
| NCEP | 45.2( 18) | 56.8( 16) | 57.8( 15) | 76.8( 15) | 102.3( 14) | 148.7( 12) | 142.9( 10) | 162.6( 8) | 130.4( 6) | 105.7( 4) | 58.3( 2) |
| ECMWF | 64.5( 9) | 62.0( 8) | 72.5( 7) | 93.8( 7) | 98.2( 6) | 117.4( 5) | 171.9( 4) | 154.0( 3) | 187.3( 3) | 184.2( 2) | 212.6( 1) |



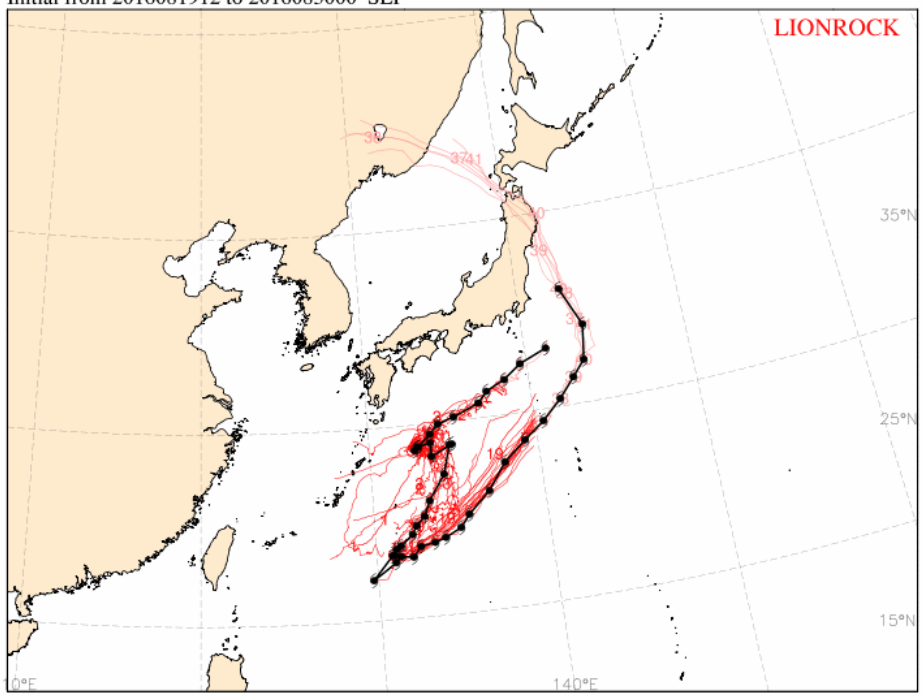

| Member/Tau | 000 | 012 | 024 | 036 | 048 | 060 | 072 | 084 | 096 | 108 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WRFM00 | 47.1(297) | 62.0(260) | 83.6(225) | 109.2(192) | 147.8(167) | 202.4(142) | 274.4(120) | 343.4( 98) | 346.2( 1) | 384.1( 1) | 324.7( 1) |
| TWRF 1.5 | 46.3(298) | 66.8(261) | 89.5(227) | 116.8(196) | 149.2(168) | 199.3(143) | 261.2(121) | 336.9( 99) | 389.7( 80) | 483.2( 65) | 661.7( 51) |
| WRFM02 | 43.2(294) | 80.4(256) | 109.3(218) | 154.4(187) | 199.2(162) | 278.6(140) | 346.9(115) | 373.3( 92) | -999.0( 0) | -999.0( 0) | -999.0( 0) |
| WRFM03 | 35.9(297) | 66.1(256) | 82.9(222) | 108.6(191) | 146.5(166) | 193.6(141) | 237.7(119) | 255.5( 76) | -999.0( 0) | -999.0( 0) | -999.0( 0) |
| WRFM04 | 75.3(273) | 72.4(236) | 84.1(206) | 104.3(176) | 138.1(150) | 181.7(128) | 227.6(106) | 258.5( 85) | 344.0( 16) | 450.4( 13) | 481.9( 9) |
| TWRF 2.0 | 51.2(282) | 59.6(246) | 79.7(218) | 103.6(189) | 134.8(165) | 175.6(141) | 221.0(118) | 242.7( 97) | 279.5( 79) | 321.5( 65) | 419.2( 51) |
| EnMultiD | 32.7(295) | 54.5(259) | 75.1(224) | 104.1(193) | 138.8(167) | 191.5(142) | 248.0(120) | 294.0( 98) | -999.0( 0) | -999.0( 0) | -999.0( 0) |
| NCEP | 32.1(272) | 48.5(242) | 74.2(210) | 107.8(183) | 141.3(158) | 195.8(136) | 252.8(114) | 307.2( 95) | 359.9( 75) | 452.6( 62) | 482.6( 49) |
| ECMWF | 47.5(144) | 50.5(126) | 60.5(107) | 83.4( 94) | 111.8( 80) | 148.5( 68) | 205.1( 57) | 254.2( 46) | 298.9( 38) | 377.2( 31) | 456.0( 24) |
| WEPS | 38.9(268) | 60.2(237) | 85.0(205) | 119.8(175) | 158.6(150) | 207.1(126) | 251.9(106) | 297.1( 86) | 371.2( 67) | 461.5( 52) | 617.7( 40) |

# Lionrock

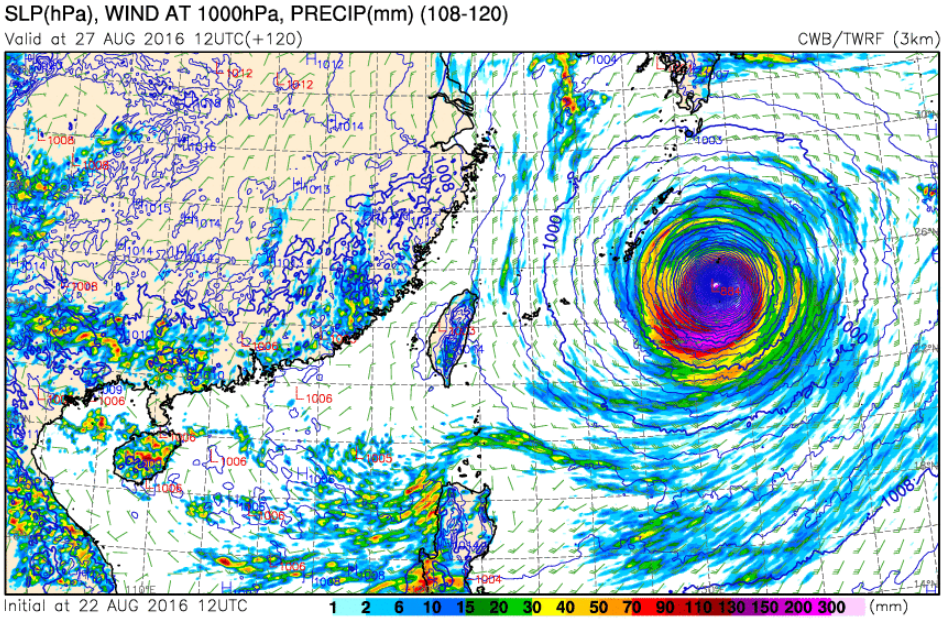
CWB/TWRF (15km) Typhoon Track Forecast
Initial from 2016081912 to 2016083000 SLP

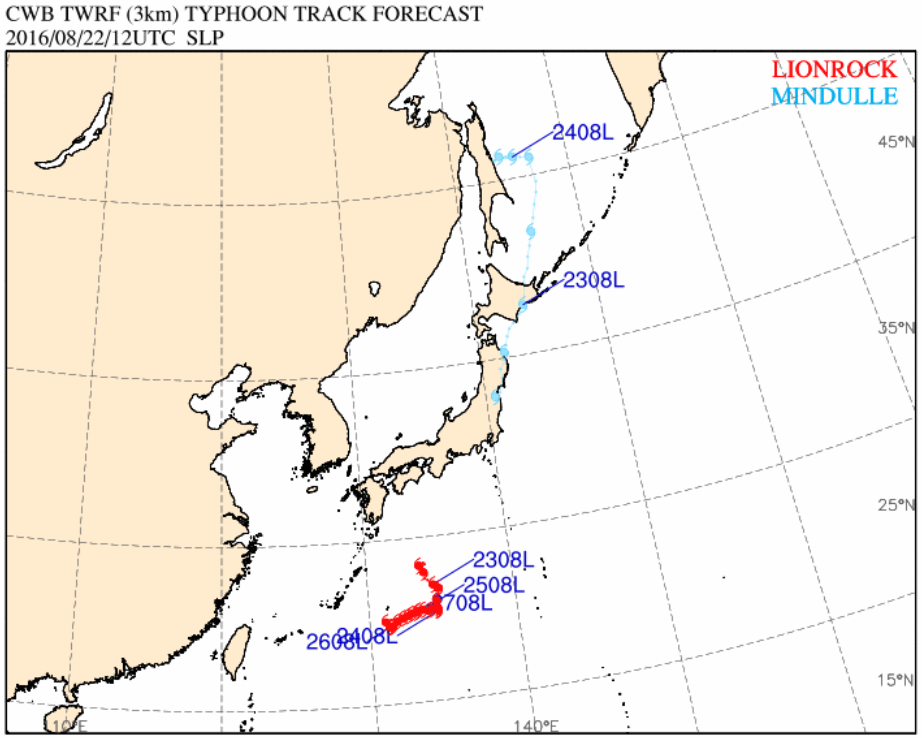



CWB/TWRF (3km) Typhoon Track Forecast
Initial from 2016081912 to 2016083000 SLP



# Lionrock




TYPHOON – LIONROCK

| TAU | LAT | LON | PMIN | km/hr |
|---|---|---|---|---|
| 0 | 28.3 | 133.6 | 993.4 | |
| 6 | 27.9 | 133.9 | 993.4 | 9.0 |
| 12 | 27.1 | 134.5 | 989.3 | 17.6 |
| 18 | 26.8 | 134.8 | 983.9 | 7.4 |
| 24 | 26.1 | 134.6 | 981.4 | 14.0 |
| 30 | 25.6 | 134.7 | 976.6 | 8.9 |
| 36 | 25.5 | 134.7 | 976.4 | 3.0 |
| 42 | 25.5 | 134.6 | 965.4 | 0.7 |
| 48 | 25.6 | 134.3 | 961.2 | 6.4 |
| 54 | 25.5 | 134.0 | 952.3 | 5.2 |
| 60 | 25.6 | 133.7 | 938.8 | 5.6 |
| 66 | 25.6 | 133.[illegible] | 924.5 | 5.6 |
| 72 | 25.5 | 133.2 | 918.7 | 3.1 |
| 78 | 25.4 | 132.9 | 907.1 | 5.3 |
| 84 | 25.3 | 132.6 | 900.6 | 5.0 |
| 90 | 25.2 | 132.2 | 893.2 | 6.2 |
| 96 | 25.0 | 131.8 | 896.0 | 7.6 |
| 102 | 24.8 | 131.5 | 891.4 | 7.0 |
| 108 | 24.7 | 131.4 | 889.6 | 2.7 |
| 114 | 24.7 | 131.[illegible] | 884.9 | 1.0 |
| 120 | 25.0 | 131.[illegible] | 884.4 | 6.7 |

TYPHOON – MINDULLE

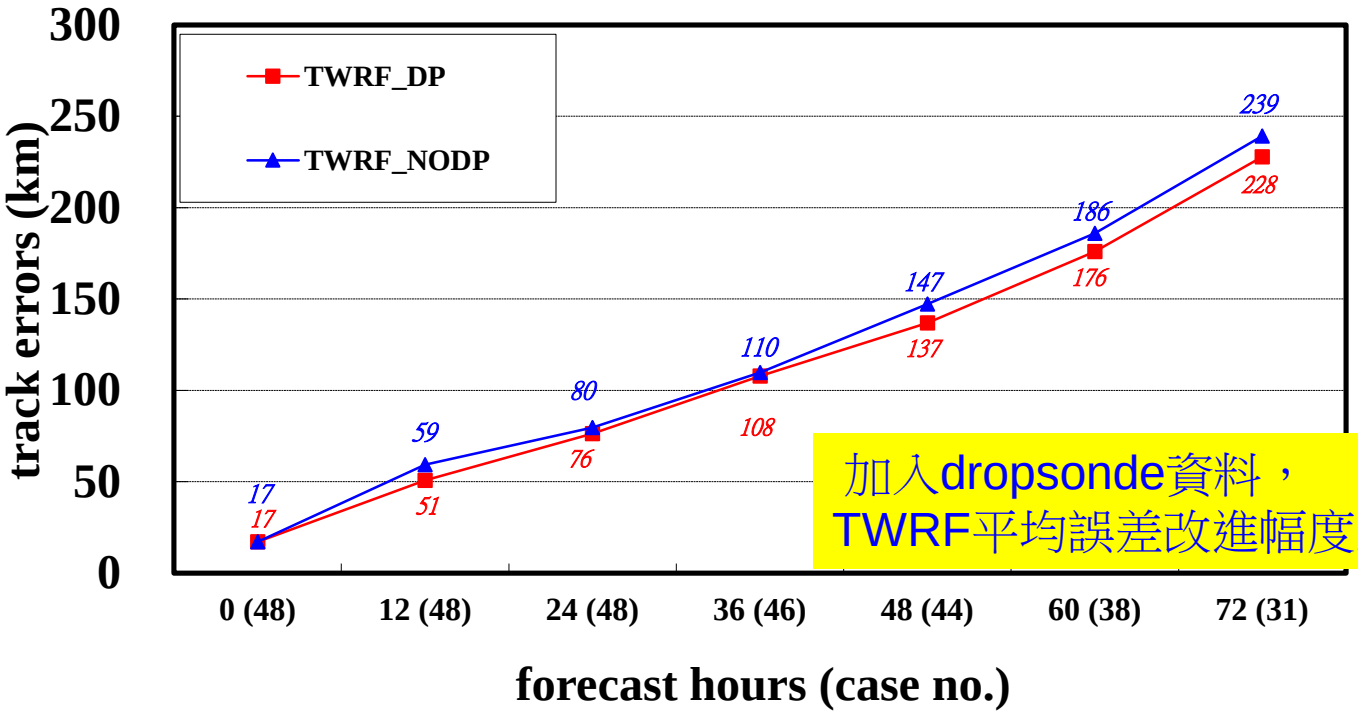
| TAU | LAT | LON | PMIN | km/hr |
|---|---|---|---|---|
| 0 | 37.8 | 140.7 | 985.0 | |
| 6 | 40.3 | 141.9 | -999.0 | 50.0 |
| 12 | 42.9 | 144.0 | -999.0 | 55.3 |
| 18 | 46.9 | 145.7 | -999.0 | 78.0 |
| 24 | 51.0 | 146.7 | -999.0 | 76.5 |
| 30 | 51.3 | 144.2 | -999.0 | 30.2 |
| 36 | 51.2 | 145.3 | -999.0 | 13.7 |

From 993 to 884 hPa within 120hrs forecast

Obs. Min. 938 hPa

積雲參數、微物理(Thompson、Ferrier、WSM6)、初始場、垂直解析度、海溫 ？

# Dropsonde Experiment result for 2008-2016
# 36TCs 48 cases




加入dropsonde資料，
TWRF平均誤差改進幅度為 **6.4%**。

# 結　論

- 今年(2016)TWRF之水平解析度由45/15/5 km提高為15/3 km，TWRF2.0(15/3km) 針對2015年之颱風個案進行測試，其路徑預報誤差優於TWRF1.5(45/15km)
- 在TWRF2.0實驗中，3km模式的路徑預報誤差比 15km模式的路徑誤差小，亦可更有效反應地形之效應
- 2016年TWRF2.0的24/48/72小時颱風路徑預報誤差分別為80/135/221 km，優於TWRF1.5、NCEP，比EC稍差
- 3km模式的颱風強度有過度預報的問題，有待進一步研究釐清
- 統計2008～2016年36個颱風共48個案，加入投落送資料，颱風路徑預報誤差改進6.4%

# 謝謝聆聽
# 敬請指教