Applications of GPS Radio Occultation Data to Tropical Cyclone Prediction

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Ching-Yuang Huang[2,3], Chan-Seng Wong[2], Chin-Tzu Fong[4], and Jing-Shan Hong[4]

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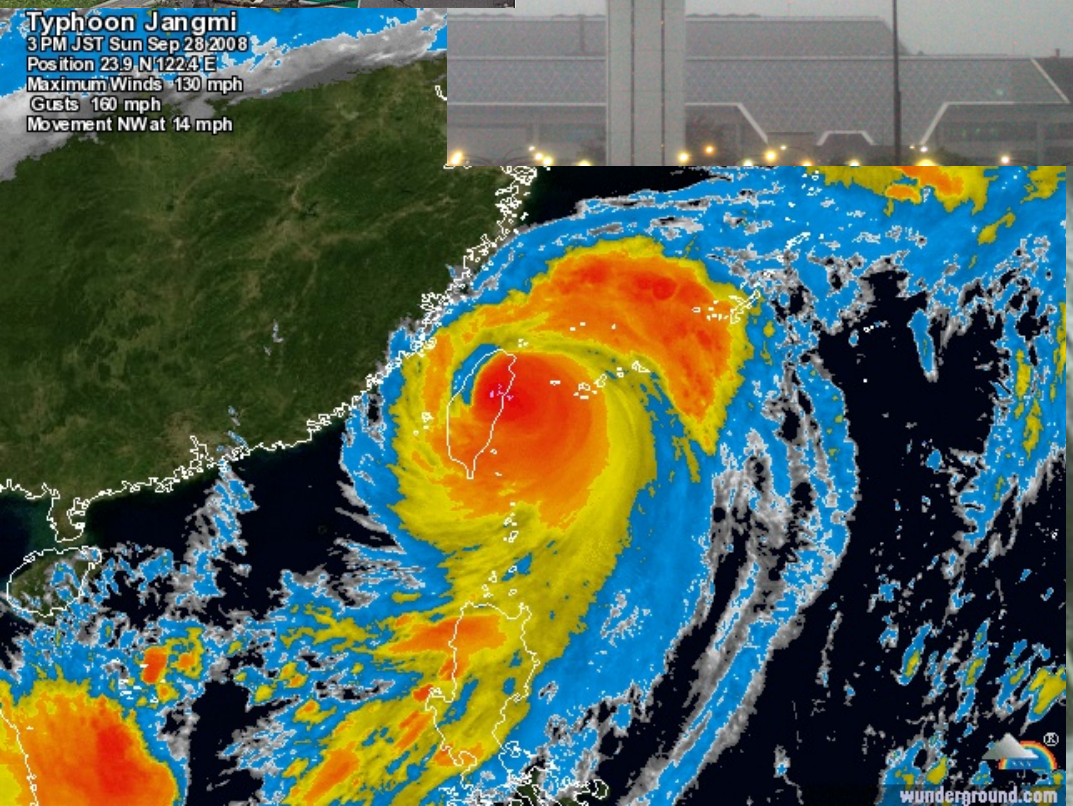
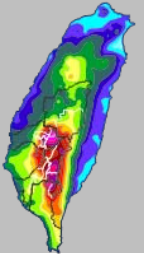
[4]Central Weather Bureau, Taipei, Taiwan

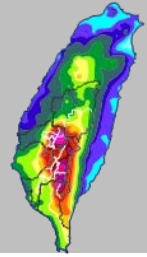
OPAC 2010, 6-9 September, GRAZ, AUSTRIA

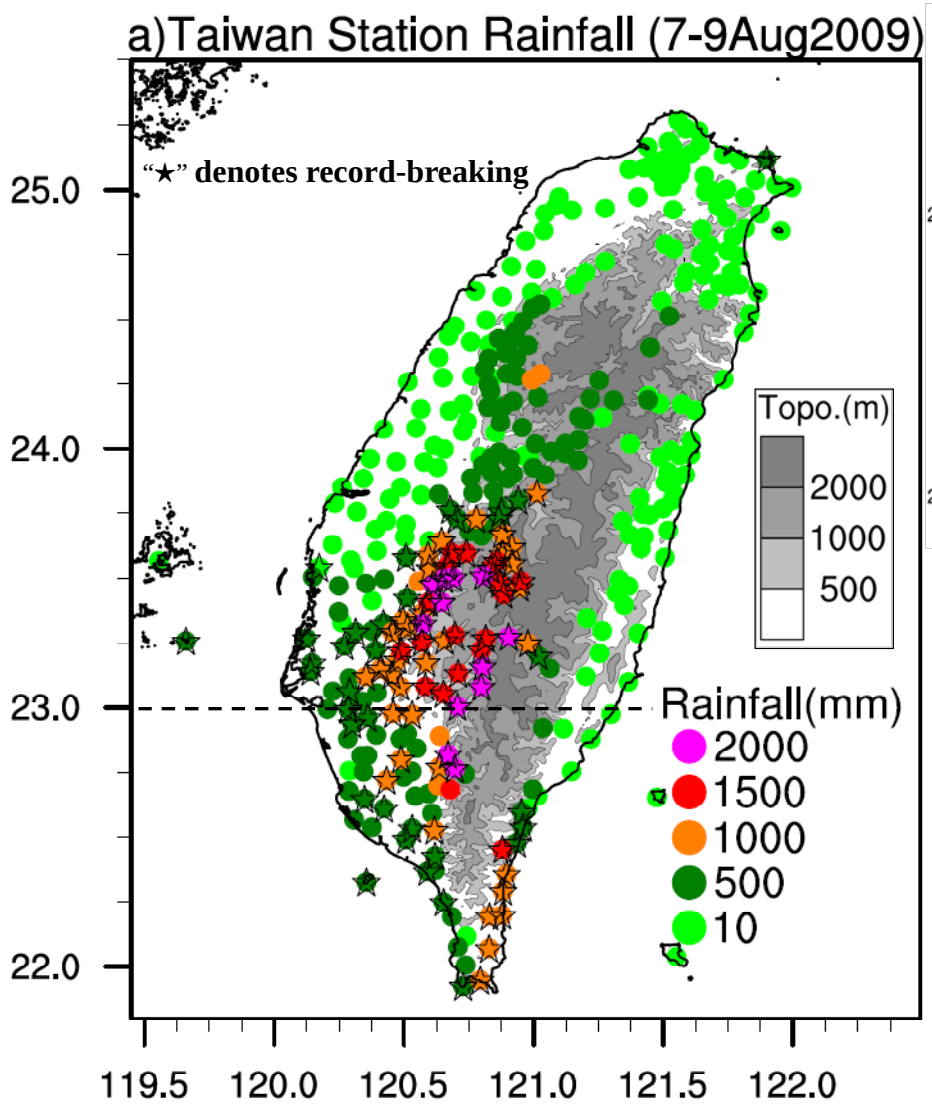
Super Typhoon Jangmi (2008)

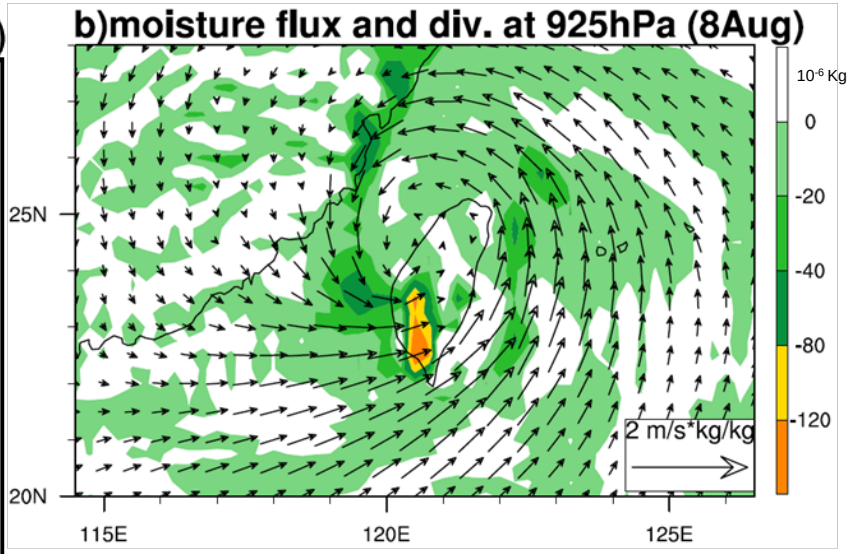


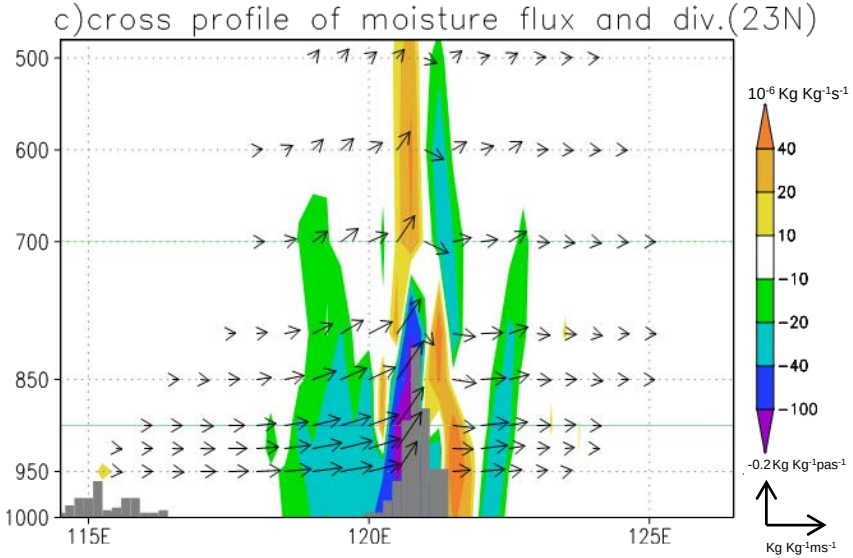
Catastrophic Morakot (2009)

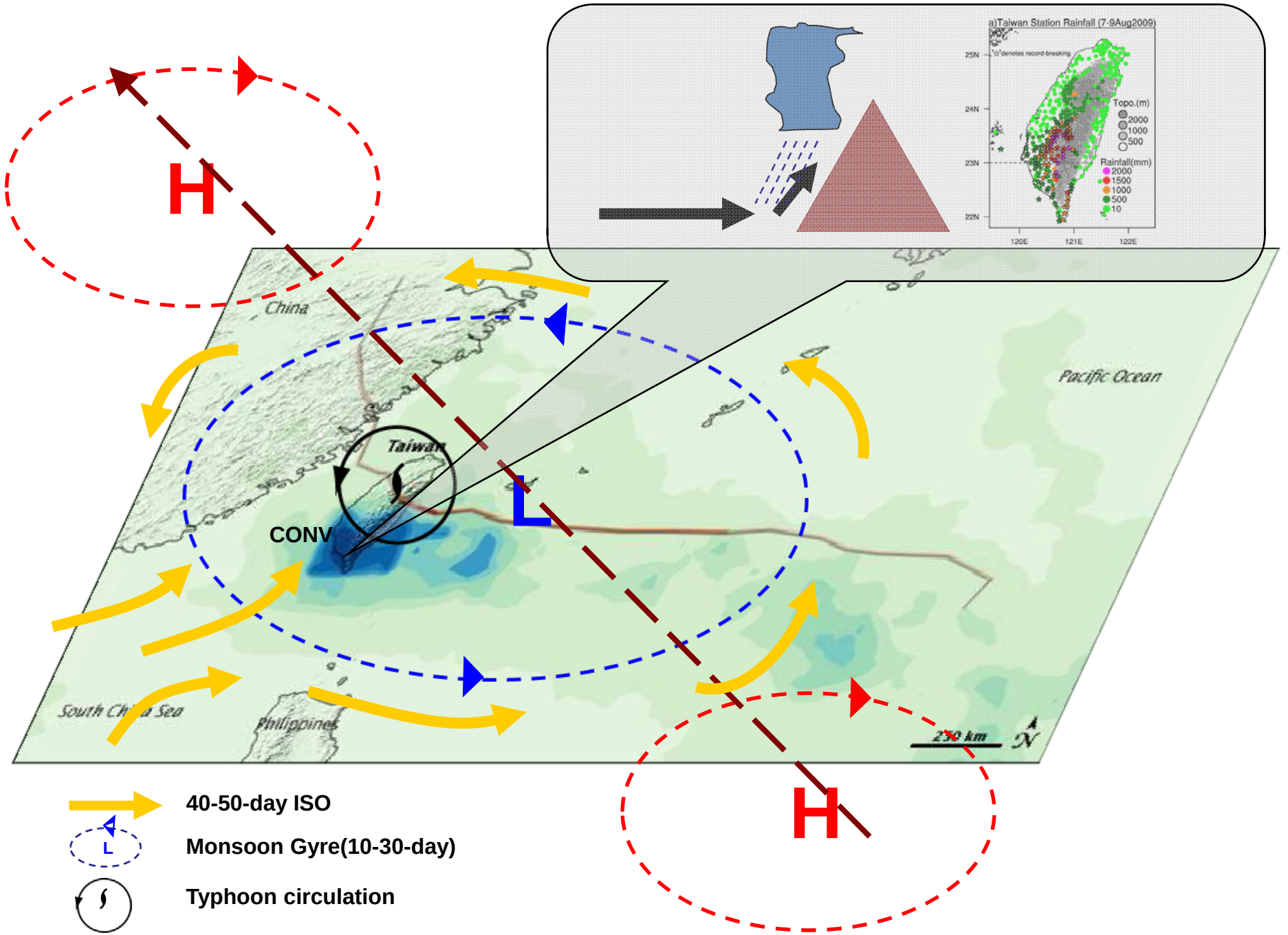








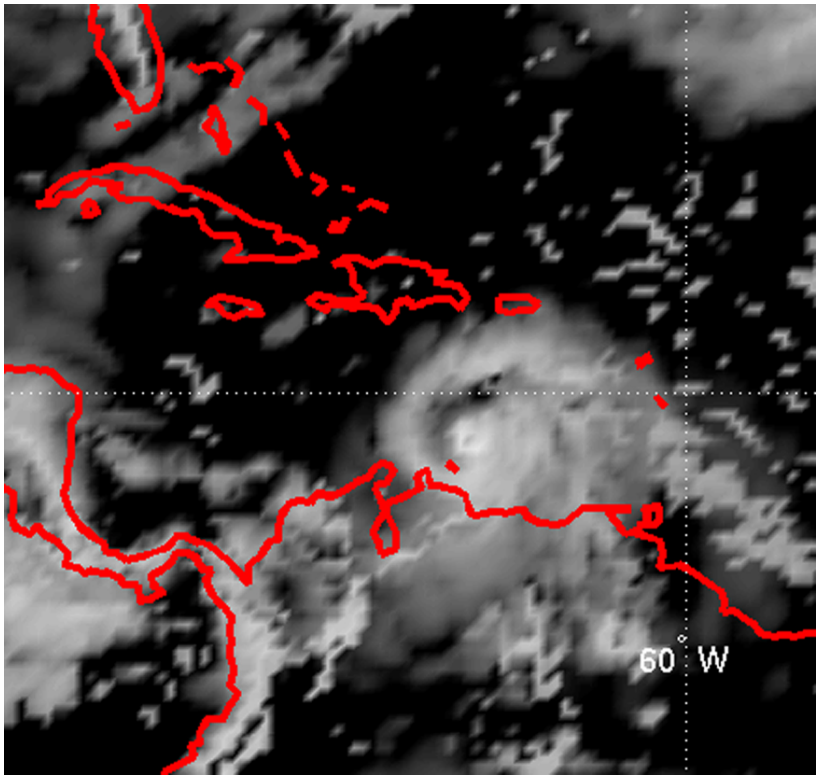



a)Taiwan Station Rainfall (7-9Aug2009)
'☆'denotes record-breaking
Topo.(m)
2000
1000
500
Rainfall(mm)
2000
1500
1000
500
10
25N
24N
23N
22N
120E
121E
122E
H
China
Taiwan
CONV
L
Pacific Ocean
South China Sea
Philippines
250 km
N
H
40-50-day ISO
L
Monsoon Gyre(10-30-day)
Typhoon circulation
Accumulated rainfall

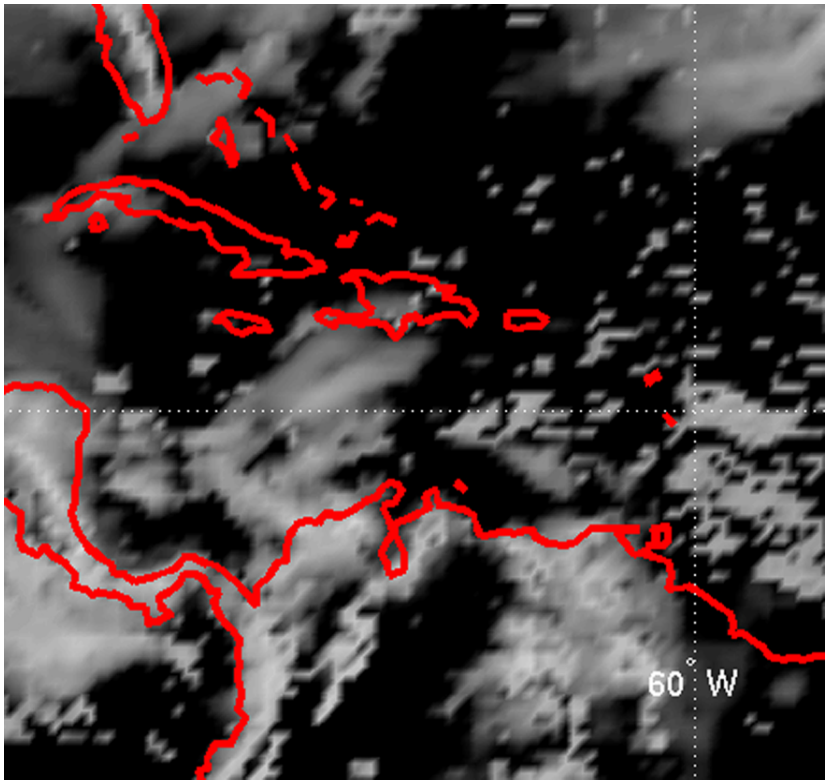
C.-C. Hong

Impact of COSMIC on Hurricane Ernesto (2006) Forecast by WRF/DART

With COSMIC



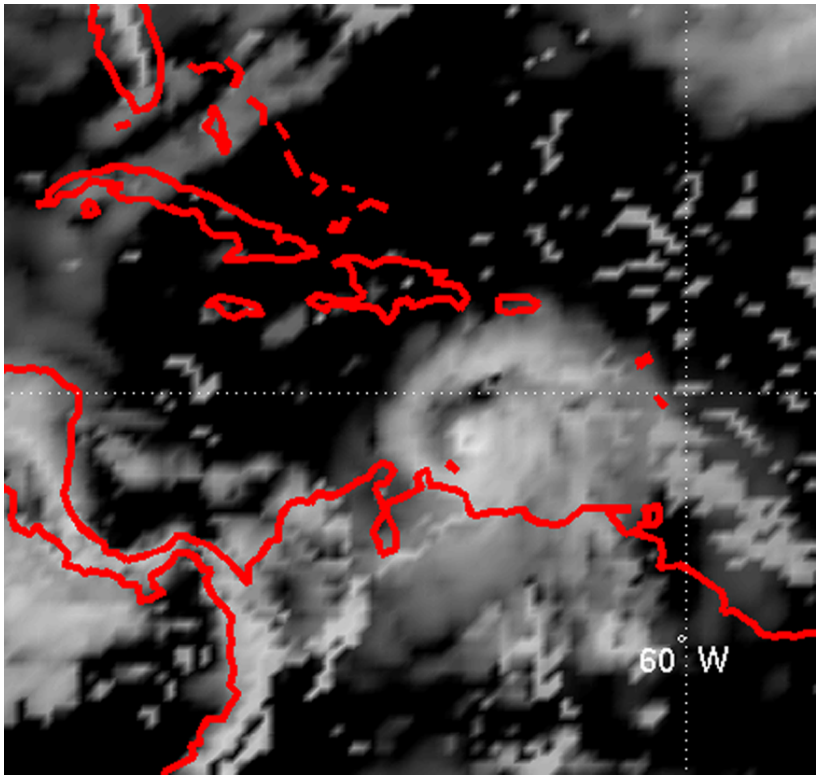
Without COSMIC



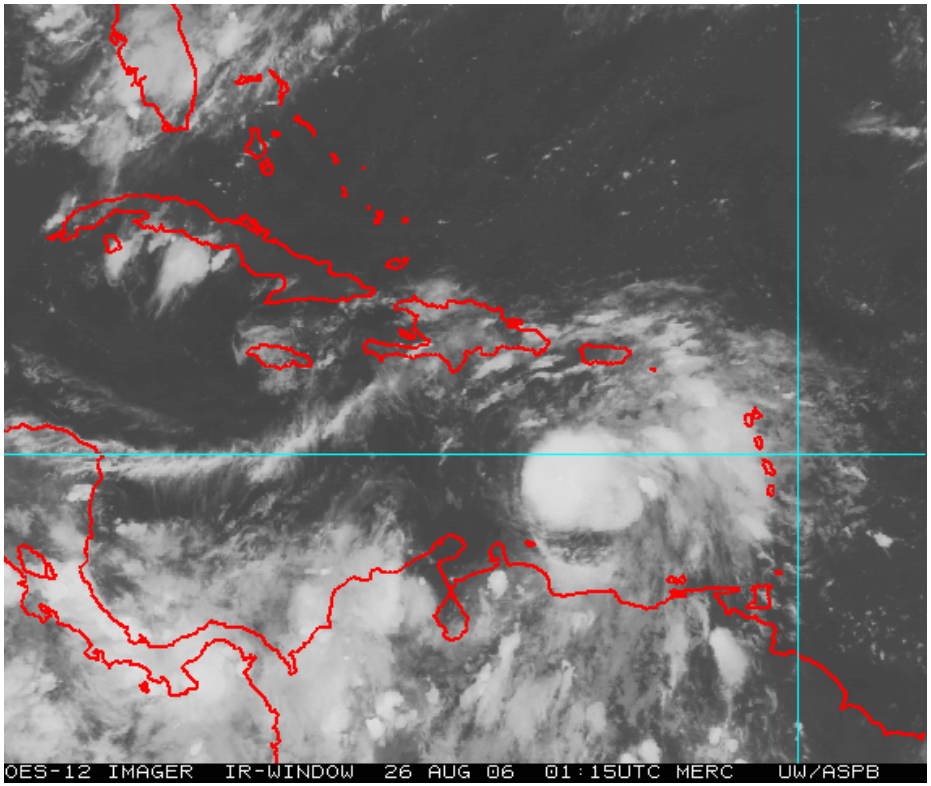
(by Y. Chen, UCAR)

Impact of COSMIC on Hurricane Ernesto (2006) Forecast

With COSMIC



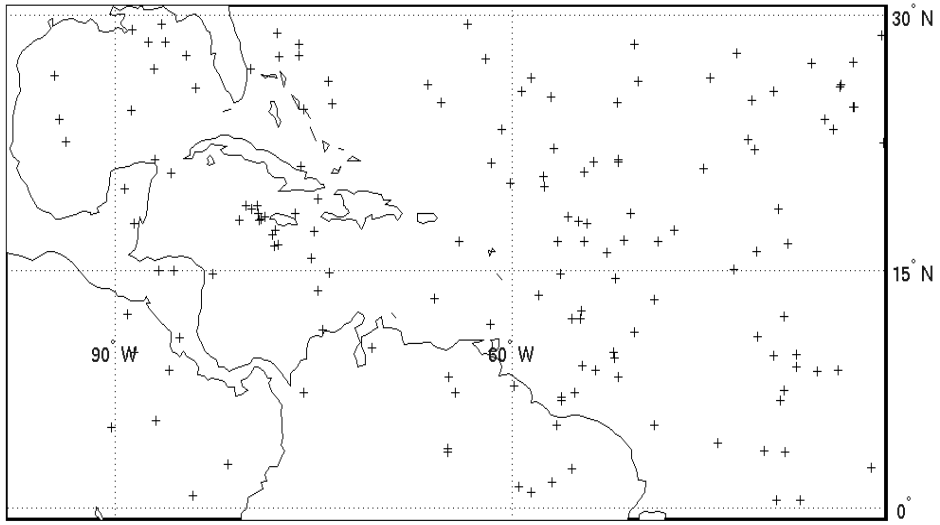
GOES Image



GOES Image from Tim Schmitt, SSEC

WRF/DART ensemble assimilation of COSMIC GPSRO soundings

- WRF/DART ensemble Kalman filter data assimilation system
- 36-km, 36-members, 5-day assimilation
- Assimilation of 171 COSMIC GPSRO soundings (with nonlocal obs operator, Sokolovskiey et al) plus satellite cloud-drift winds
- Independent verification by ~100 dropsondes.



171 COSMIC GPSRO soundings during 21-25 August 2006

With COSMIC

No COSMIC

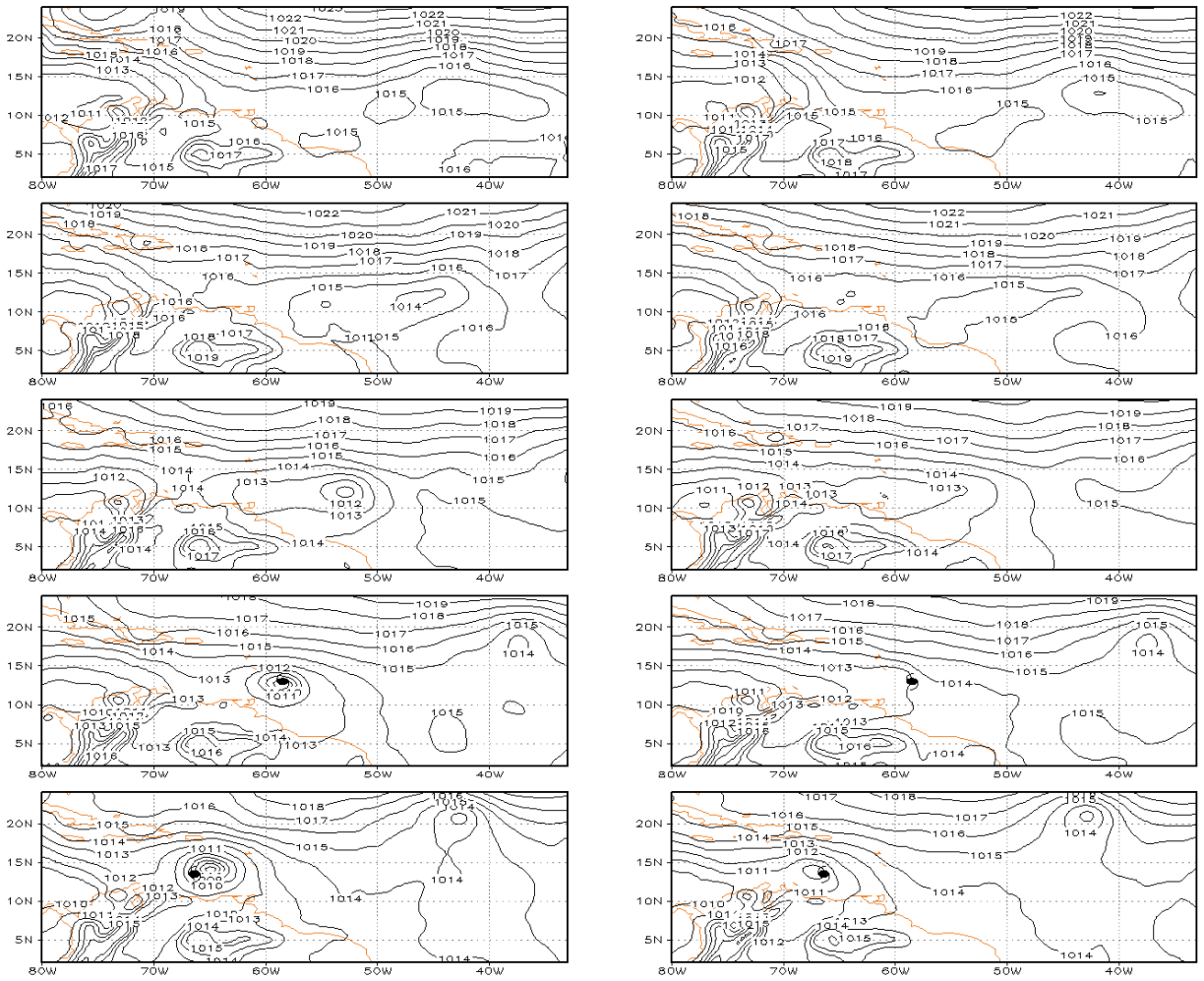
06/8/21 12Z

06/8/22 12Z

06/8/23 12Z

06/8/24 12Z

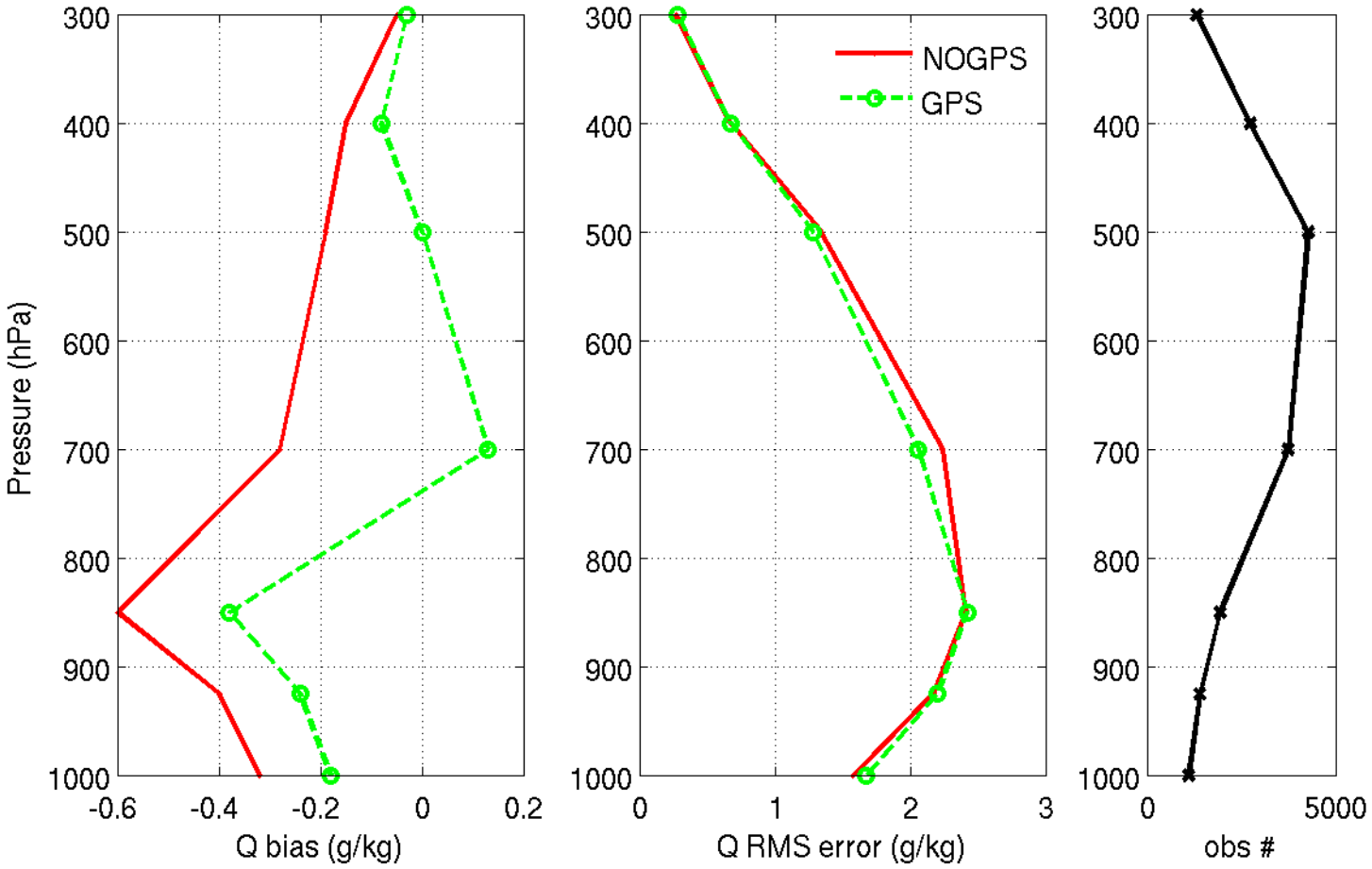
06/8/25 12Z



Genesis of Hurricane Ernesto (2006)

Continuous data assimilation during genesis stage with WRF EnKF system

Verification of WRF/DART analysis by about 100 dropsondes during the Ernesto genesis stage.



(from Hui Liu)

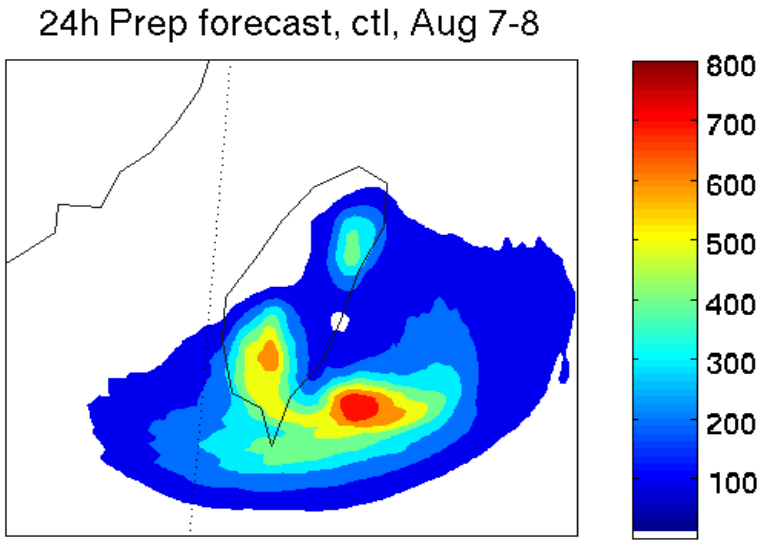
WRF/DART Configuration at CWB

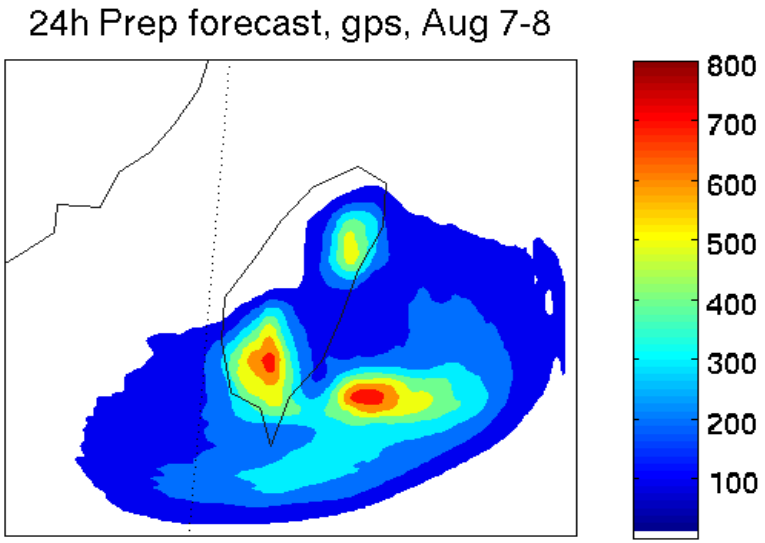
- DART EAKF algorithm, 32 members, CWB 45km grid
- DART Adaptive ensemble inflation, fixed localization
- CWB operational WRF namelists setting
- CWB operational data, including radiosondes, aircraft data, satellite cloud winds, TC bogus data, TC position data, satellite thickness data, GPS RO refractivity.

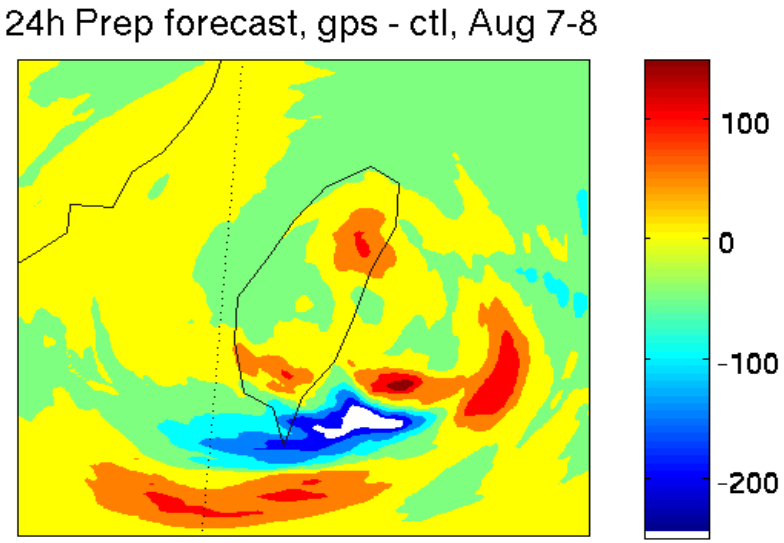
Assimilation experiments for Morakot

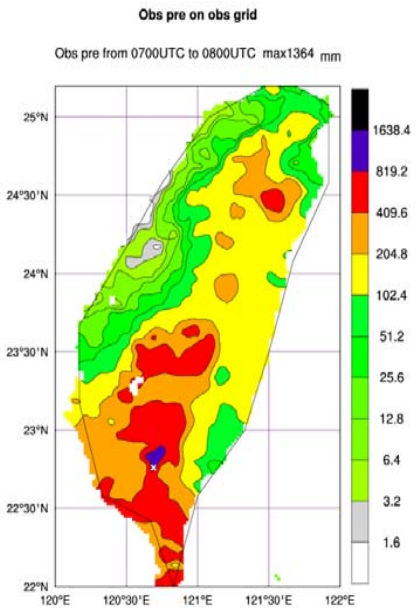
- Assimilation from 00Z 3 to 18Z 8 August, 2009 with 2-hourly cycling.
- 36km analysis grid
- 48h Forecast with nests 36/12/4km starting at August 7 00Z.
- CTL run: Assimilate CWB conventional observations
- GPS run: CTL run + COSMIC refractivity data.

24h forecast of 24-h accumulated rainfall (Aug 7-8)

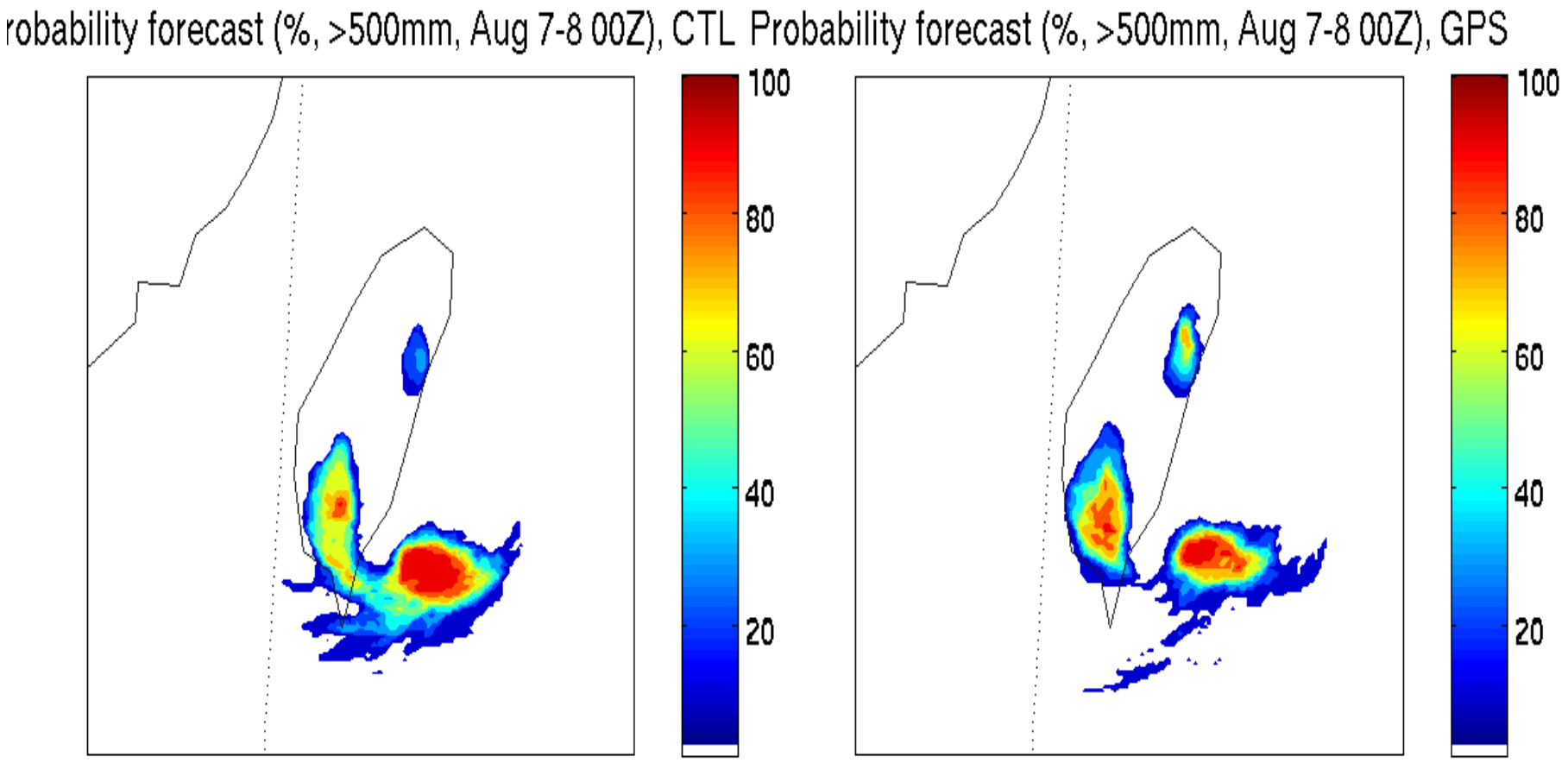








Rain Probability Forecast (August 7-8 00Z)

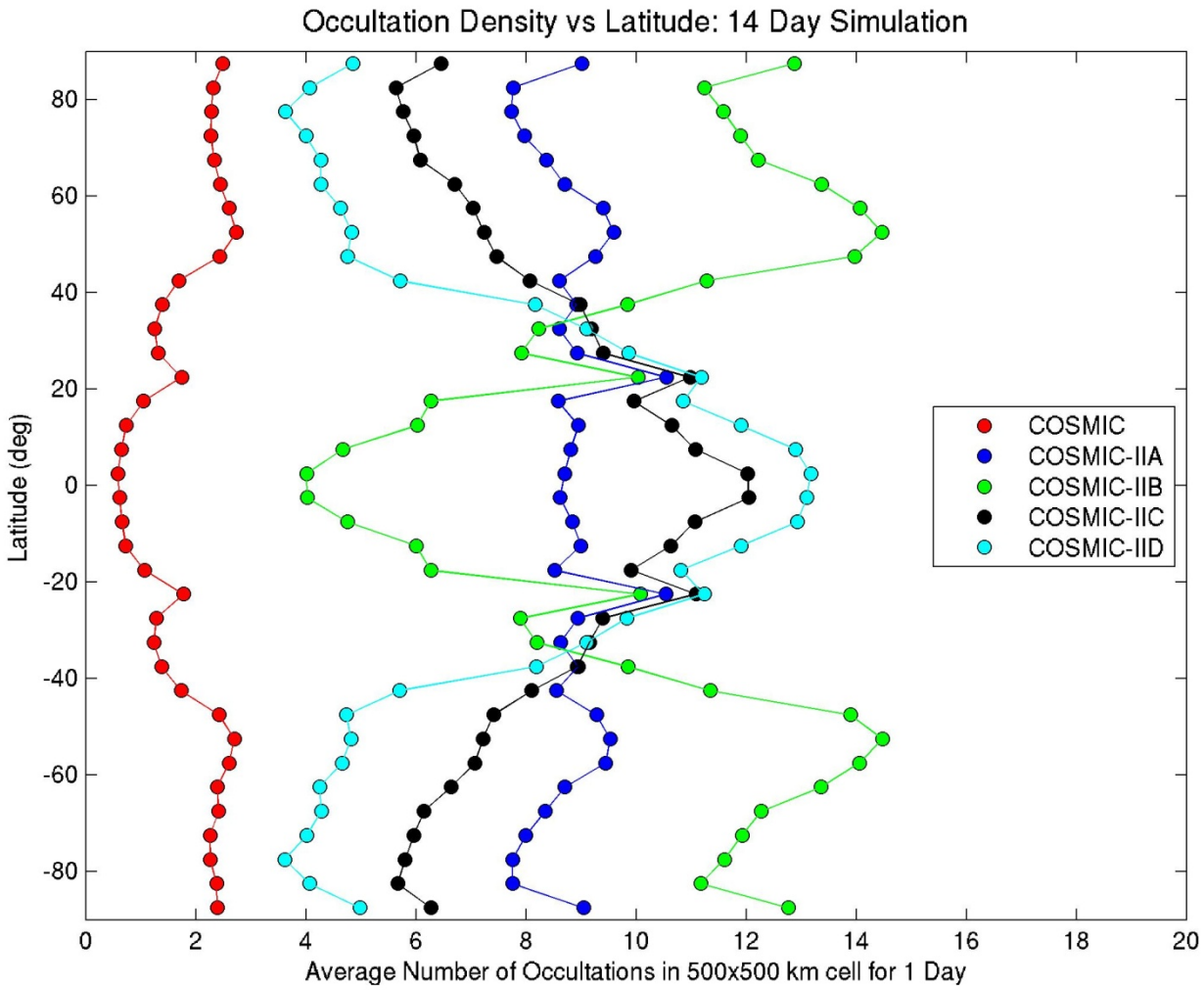


Track errors of 48h forecasts (August 7 - 9 00Z)

Ensemble forecasts from 00UTC 7 August, CTL

Ensemble forecasts from 00UTC 7 August, GPS

Data Density for COSMIC and COSMIC-II Options: A, B, C, and D



COSMIC
- 6 x 72°

COSMIC-IIA
- 8 x 72° + 4 x 24°

COSMIC-IIB
- 12 x 72°

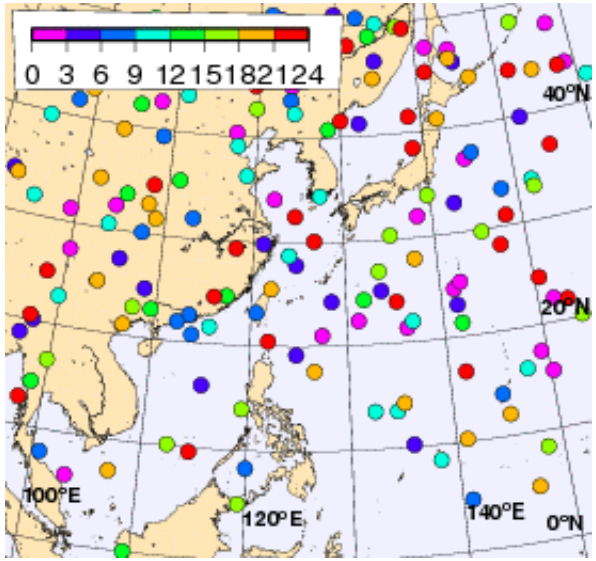
COSMIC-IIC
- 6 x 72° + 6 x 24°

COSMIC-IID
- 4 x 72° + 8 x 24°

Distribution of RO soundings in a day

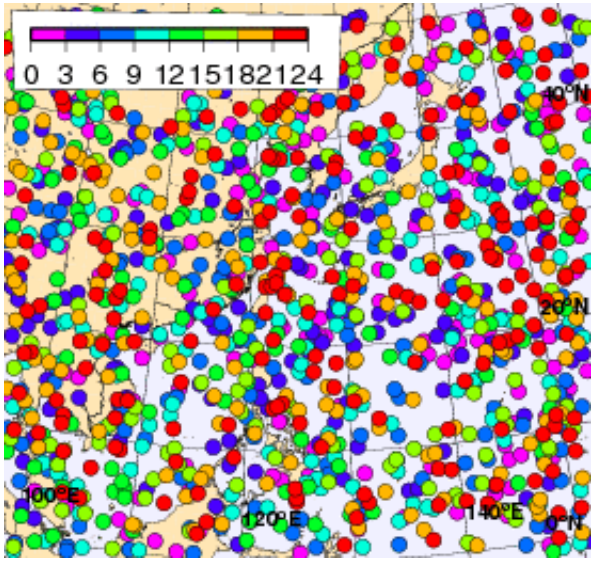
G

FORMOSAT-3/COSMIC



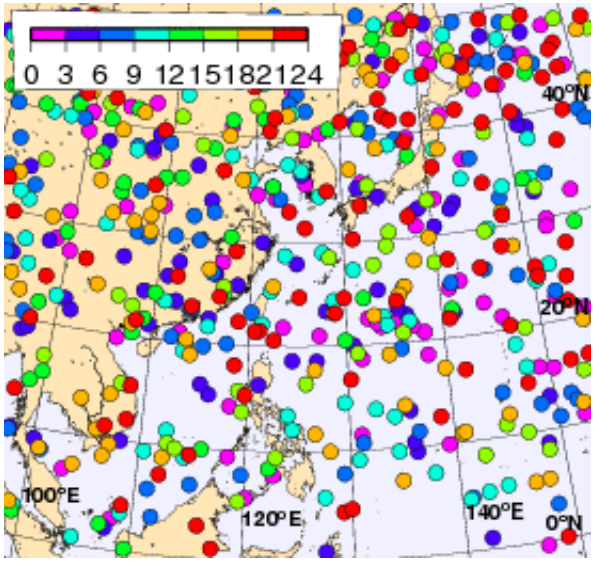
A

COSMIC-IIA



B

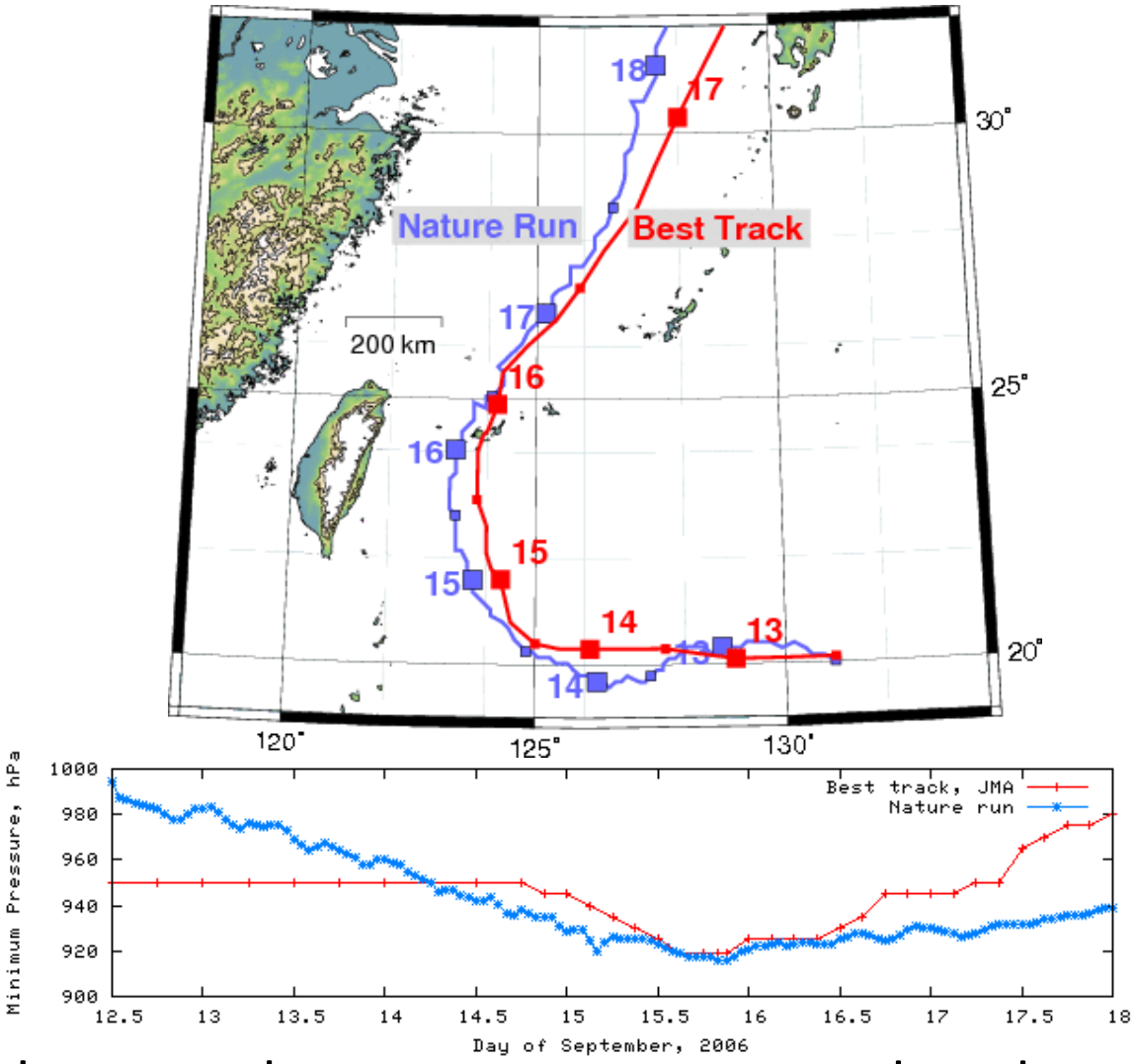
COSMIC-IIB



Different color shows availability of RO soundings at different hours of the day.

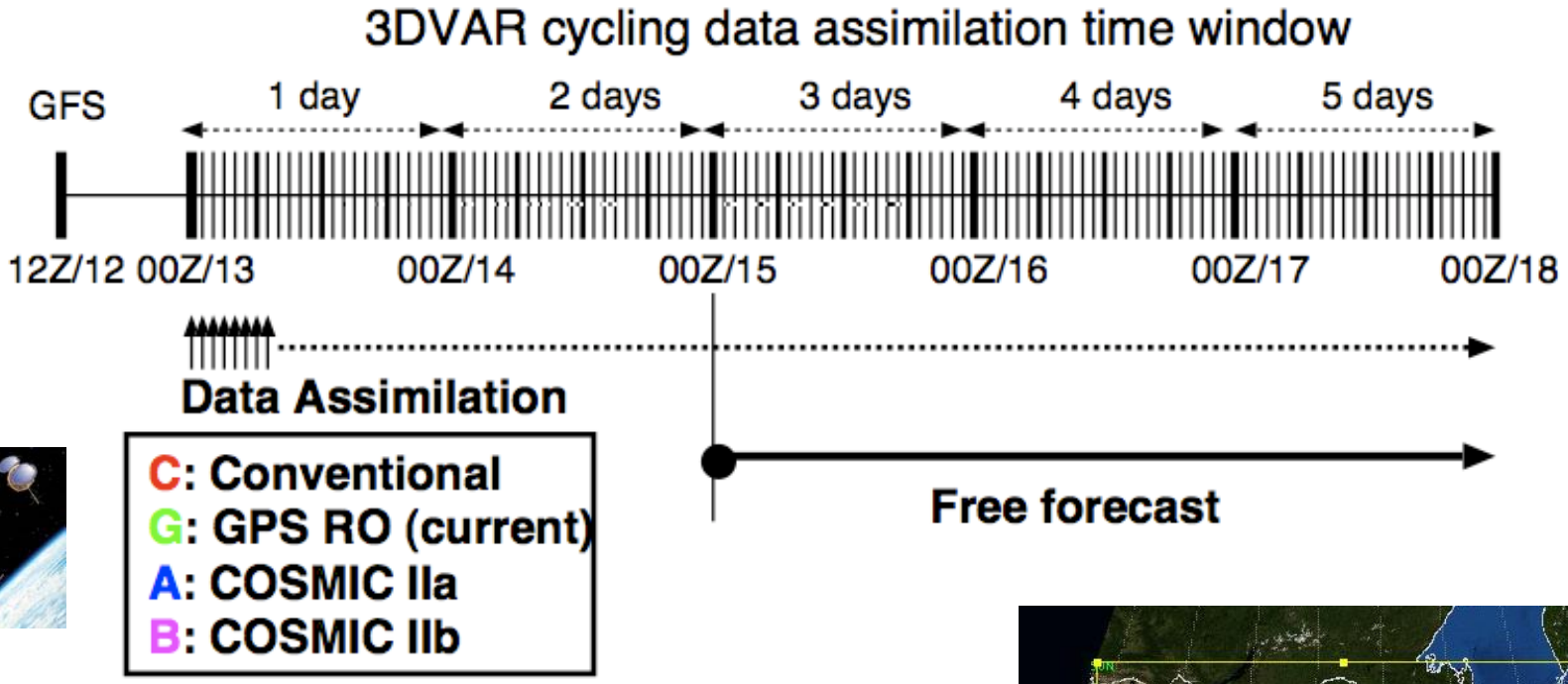
(from Bill, UCAR)

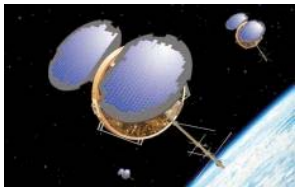
Nature Run from MM5 with ECMWF Initial condition



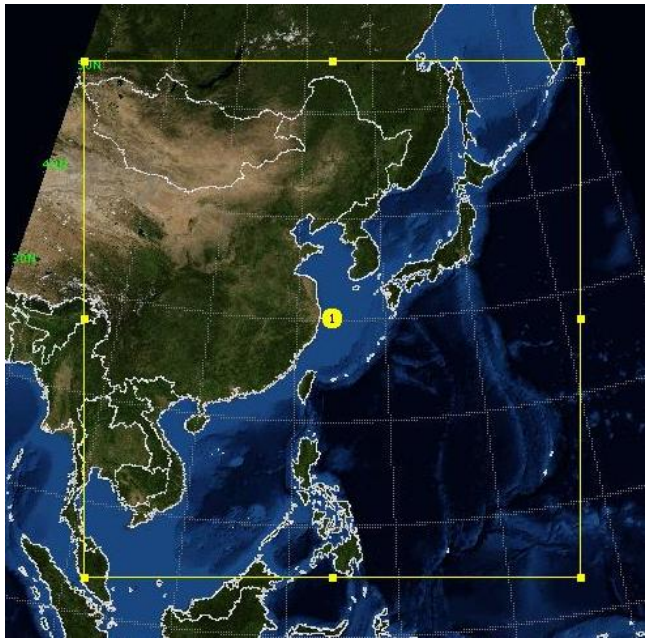
- Typhoon track recurvature was reproduced
- The track is close to the best track
- Note that no official intensity observation is available

Forecast Experiment Design



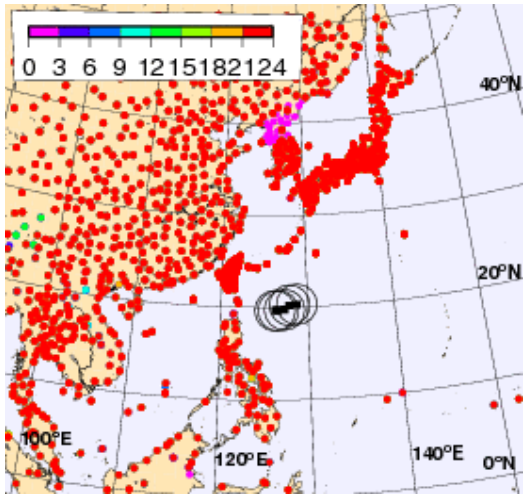


- WRF-Var (3D-Var) /WRF with GFS IC and LBC
  - B.E.: generated from one month forecast of September, 2006 (NMC)
  - 169 x 157 x 38, ptop = 10 hPa
  - Assimilation performed on 36-km grid, 1hr update cycle, over two-day period.

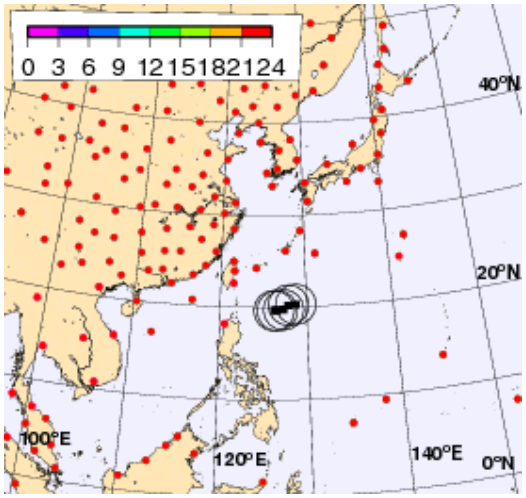


Convention Data Are Assimilated As Well

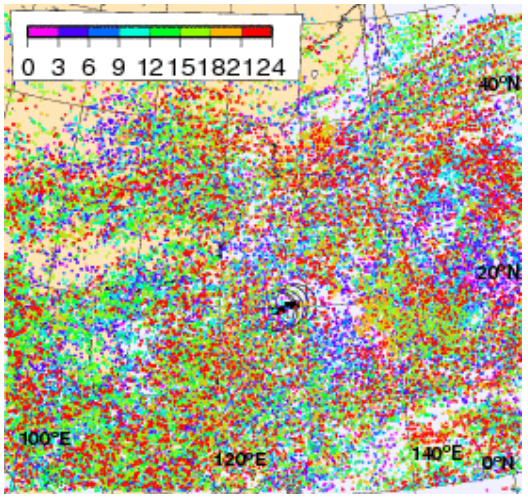
Synop



SOUND upper air

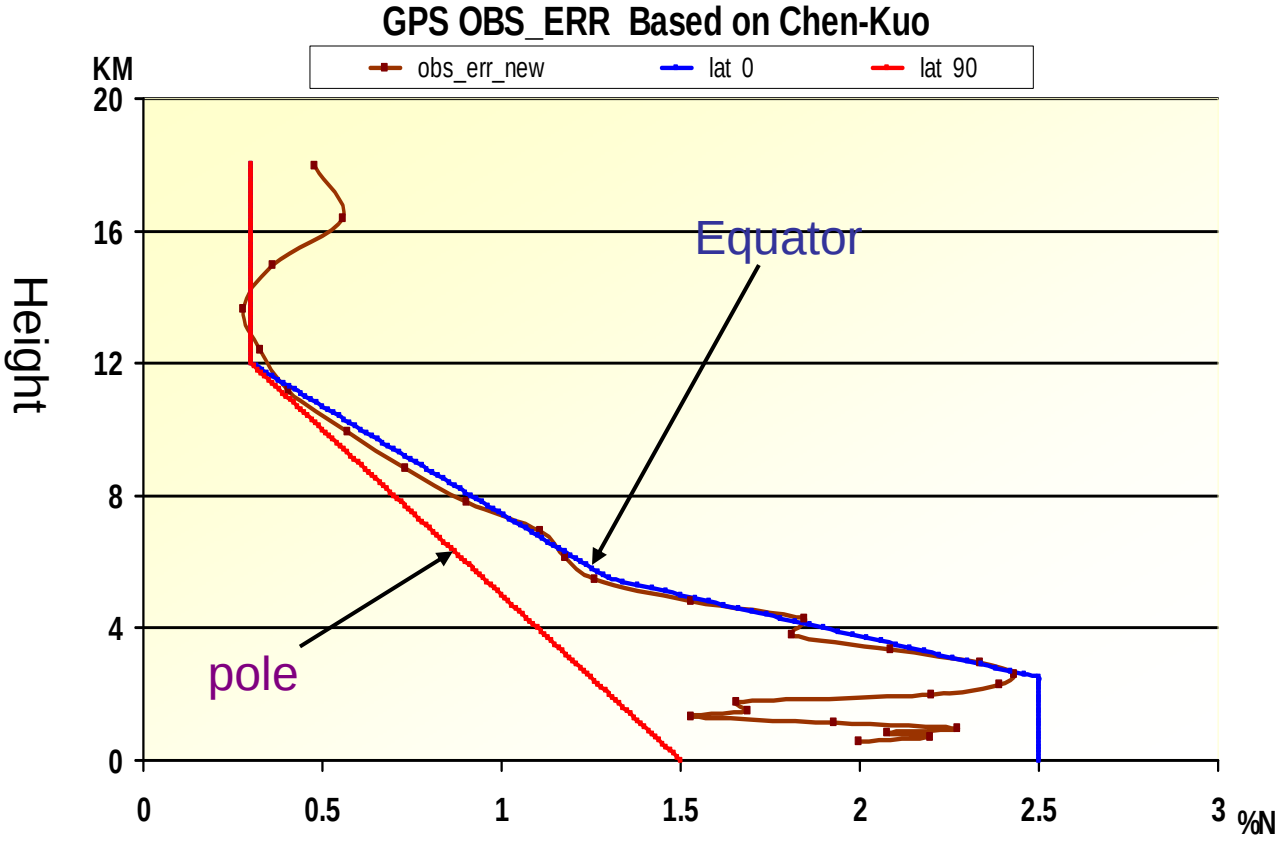


Satellite wind (SATOB)



- Upper Air sounding (SOUND)
- Observation (SYNOP)
- Satellite Cloud track Wind (SATOB)
- The horizontal and temporal distribution of these data are consistent with actual observations (location/time, and with realistic errors)

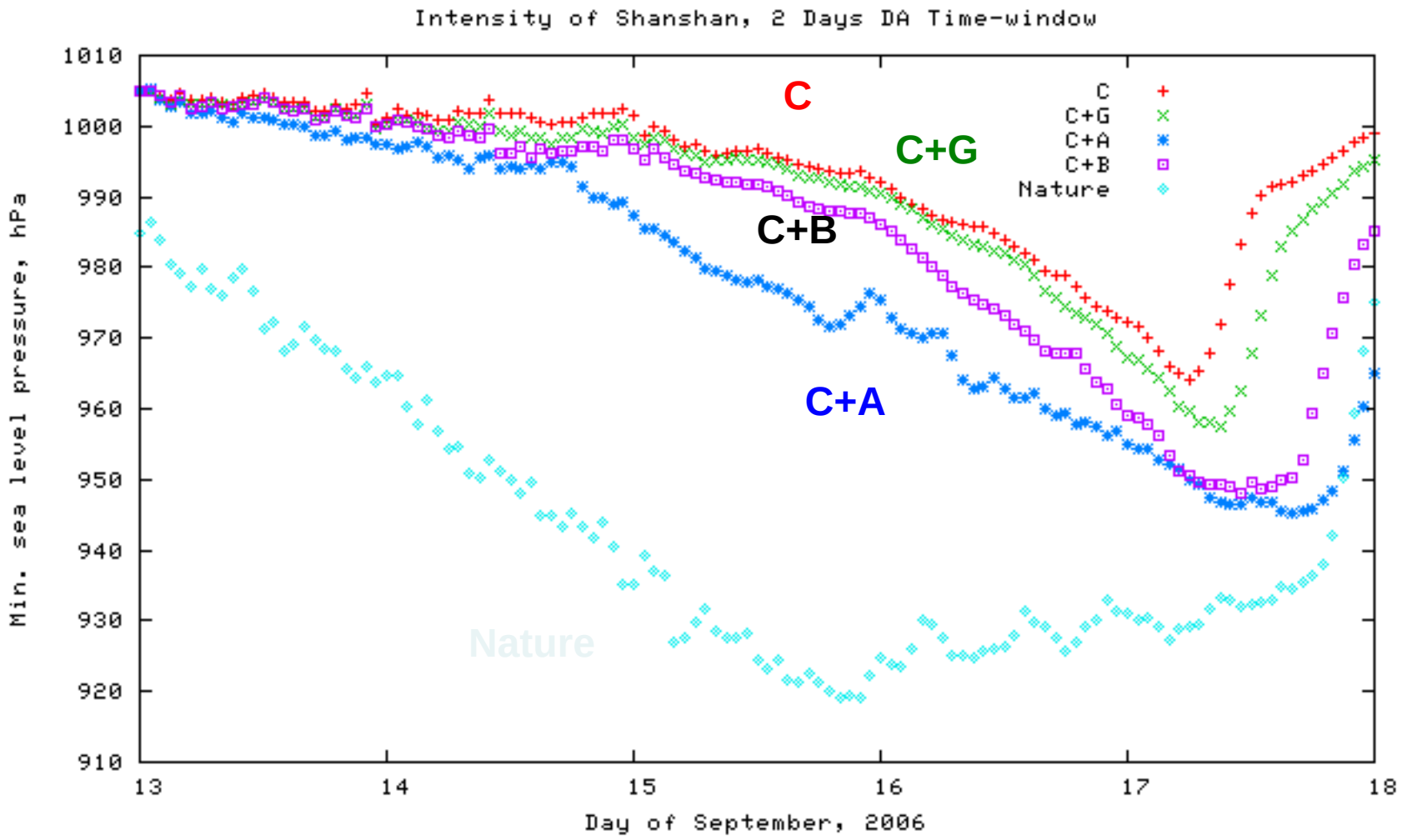
Simulated RO Refractivity Data



Percentage of GPS Ref observations

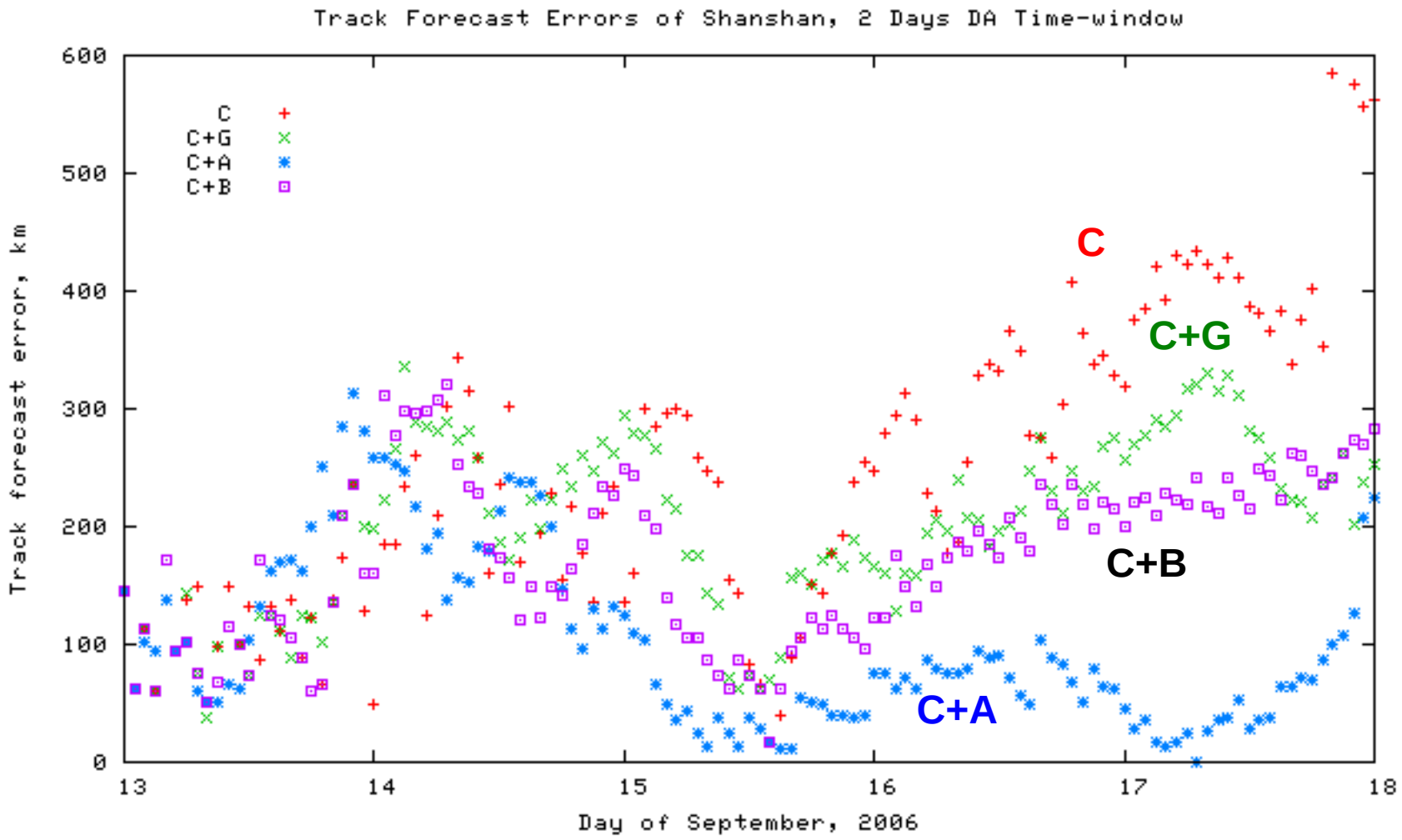
- For GPSRO refractivity, the observation errors vary with *height and latitude* (Chen and Kuo, 2005).
- RO soundings are simulated from the nature run as local value, no ray tracing simulation.

Intensity Forecast



- Intensity Forecast Performance: **C+A** > C+B > C+G > C

Track Forecast Errors



- Performance: **C+A** > C+B > C+G > C

Track Forecast Errors

Improvement against control (conventional data) forecast

Percentage of improvement of track forecast

Forecast	C+G	C+A	C+B
0 ~ 1 day	9.5	75.8	36.7
1 ~ 2 day	29.0	74.7	37.5
2 ~ 3 day	36.3	86.9	44.4
Mean	**25.0**	**79.1**	**39.5**

- FORMOSAT-3 only shows visible improvement over Control.
- COSMIC-IIA shows significant improvements over control.
- COSMIC-IIA is superior to COSMIC-IIB

Outlook

- Current COSMIC sounding distribution is NOT optimal for tropical prediction. We have the lowest data density over the tropics.
- Future mission (e.g., COSMIC-II) will substantially increase the data density over the tropics (factor of 10).
- UCAR, under sponsorship of NSF, will be conducting an OSSE study to examine the impact of COSMIC-II on Typhoon Morakot.

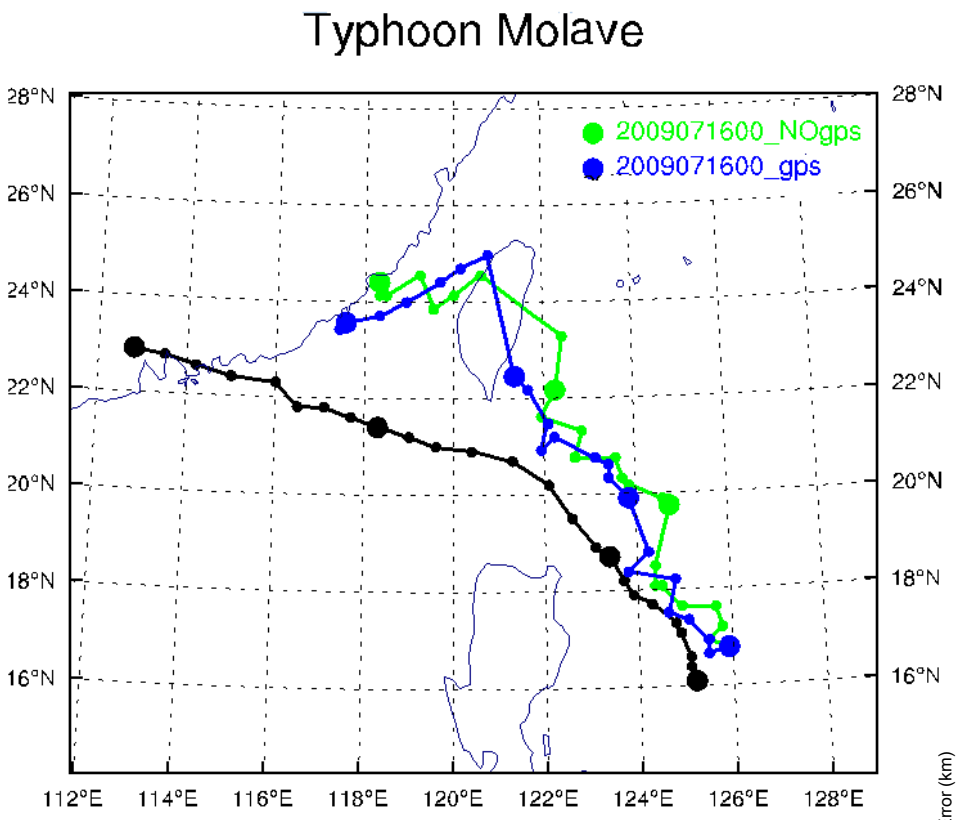
Typhoon track error ratio

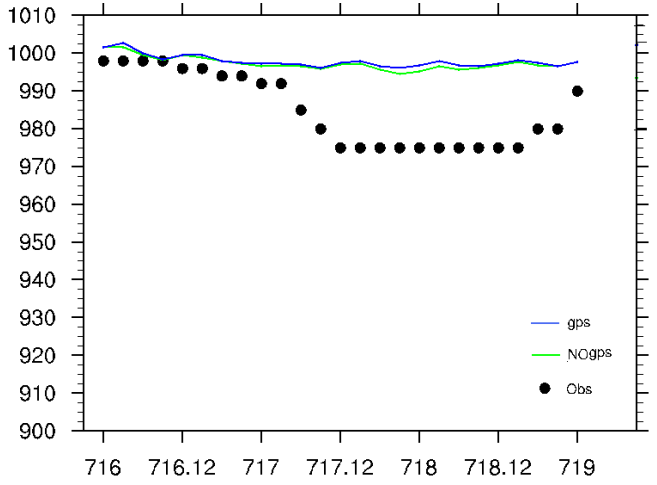
= EXP track error/None track error

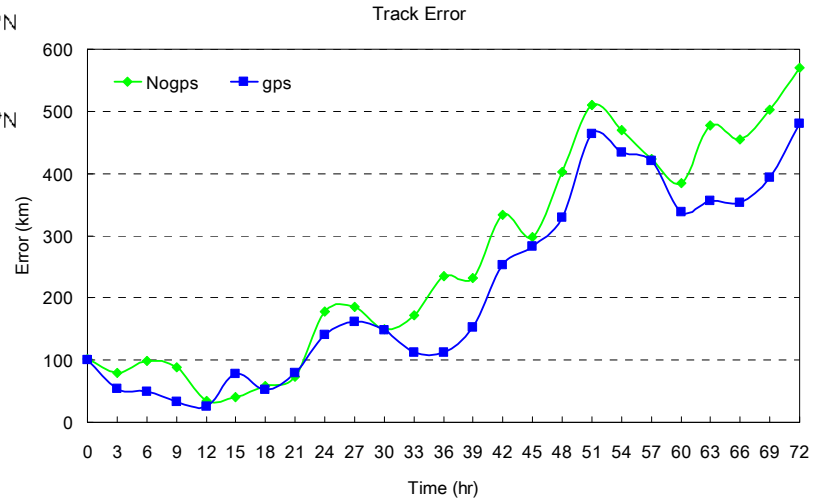
	Kalmaegi (2008)					Fung-Wong (2008)					Jangmi (2008)			
	EPH	Drop	CGTS	SSMI	QSCAT	EPH	Drop	CGTS	SSMI	QSCAT	EPH	Drop	CGTS	SSMI
0h	0.98	1.67	0.92	0.97	0.91	1.02	1.42	1.15	1	1.05	1.02	1.37	1.07	0.99
6h	0.96	1.34	1.01	1.01	1.00	1.12	1.81	1.46	1.01	0.33	1.71	3.65	0.75	1.55
12h	0.91	1.66	0.73	0.91	0.85	1.26	1.26	3.35	0.54	0.45	1.64	1.87	1.13	0.75
18h	0.84	1.89	0.74	0.73	0.81	0.74	0.78	0.22	0.85	0.23	1.76	1.63	1.2	1.09
24h	0.80	2.20	1.07	1.14	0.69	1.76	3.67	5.5	4.64	2.6	10.9	5.87	1.36	2.69
30h	0.94	2.83	0.76	0.88	0.58	0.05	0.71	1.03	0.16	1.15	2.66	1.43	0.29	0.93
36h	0.93	2.50	0.68	1.04	0.70	1.23	1.05	0.42	0.79	0.76	3.22	1.35	0.79	1.15
42h	0.96	2.14	0.80	0.99	0.75	3.53	3.91	0.89	1.56	0.82	4.11	1.38	1	1.39
48h	0.95	2.07	0.64	1.06	0.77	0.59	0.9	0.77	0.56	0.82	3.15	0.54	0.35	0.63
54h	0.97	1.96	0.78	1.01	0.77	2.57	1.99	0.87	1.07	1.63	2.35	0.77	0.54	1.07
60h	0.98	1.93	0.74	1.01	0.80	3.27	3.83	1.39	0.39	0.95	2.13	0.89	0.63	1.08
66h	0.95	1.89	0.81	0.97	0.84	3.89	5.88	0.88	1.17	3.31	2.18	1	0.59	1.22
72h	0.95	1.94	0.78	0.94	0.85	1.24	2.52	1.43	1.13	0.97	2.06	1.01	0.68	1.08

Molave typhoon

Initial time:2009-07-16-00:00

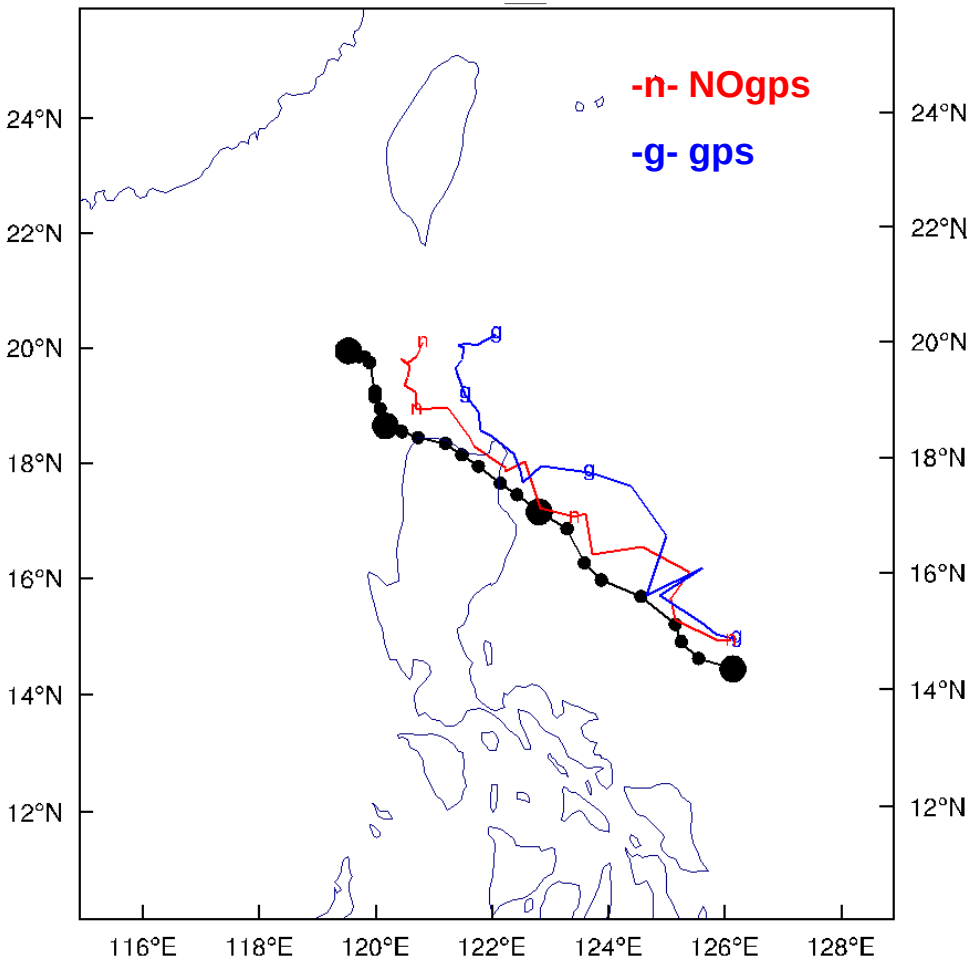


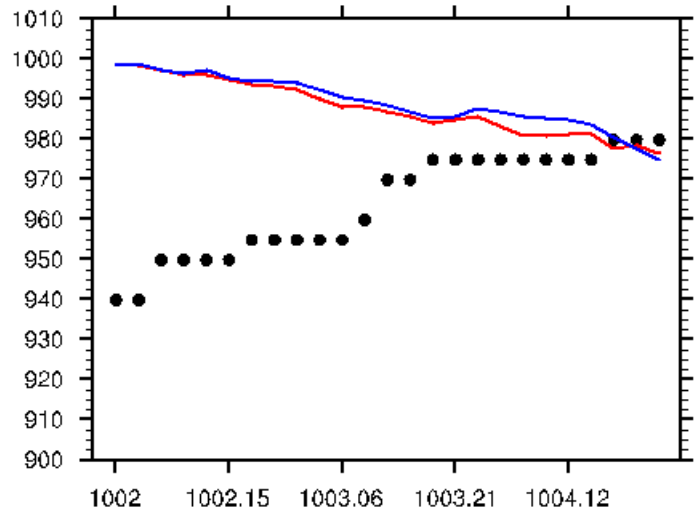


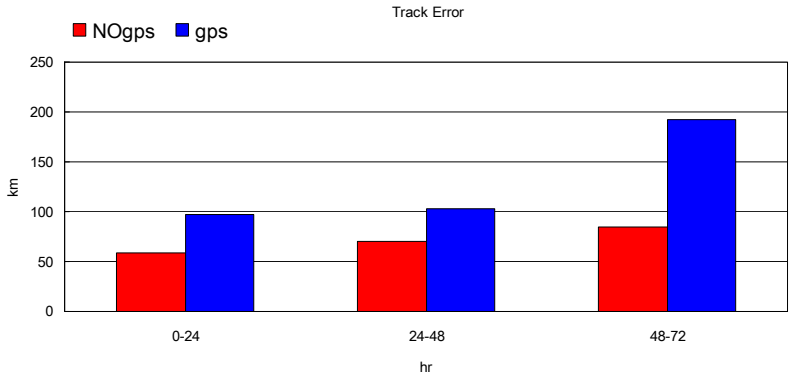


Parma typhoon

Initial time:2009-10-02-00:00

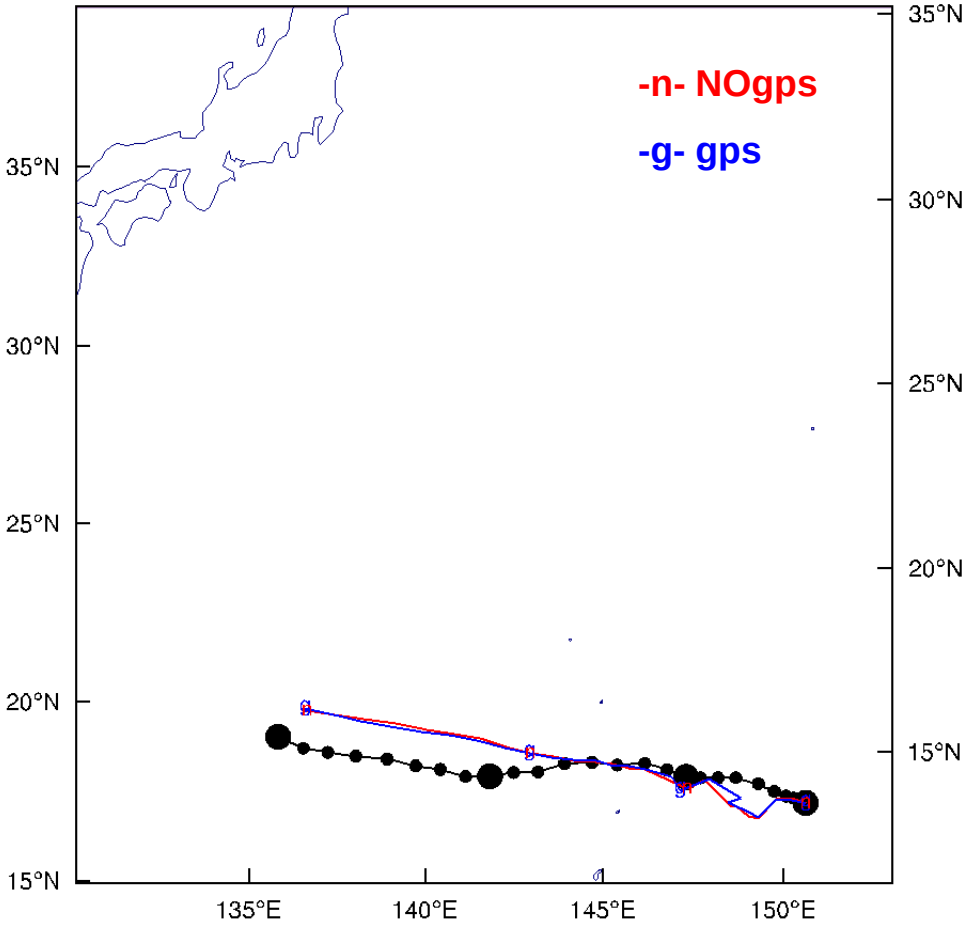


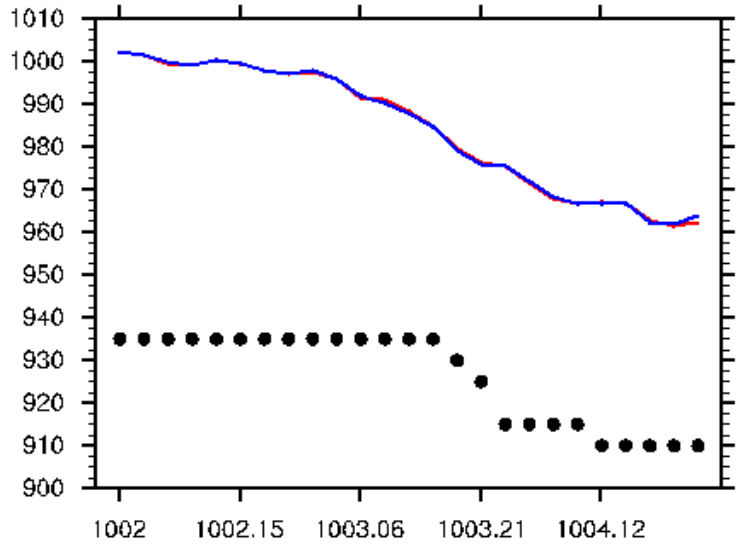


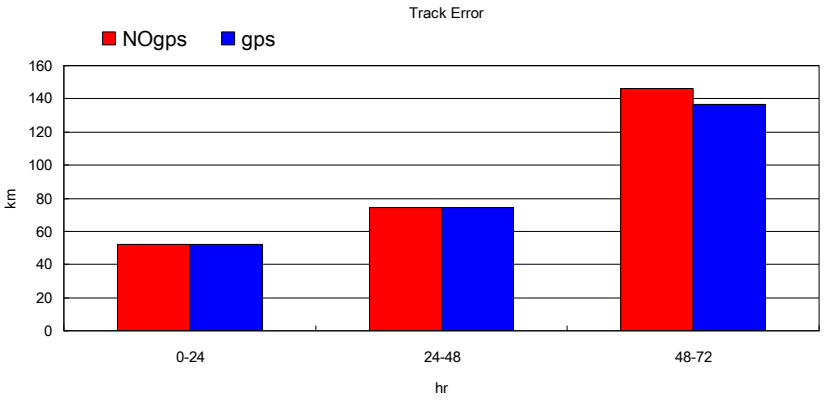


Melor typhoon

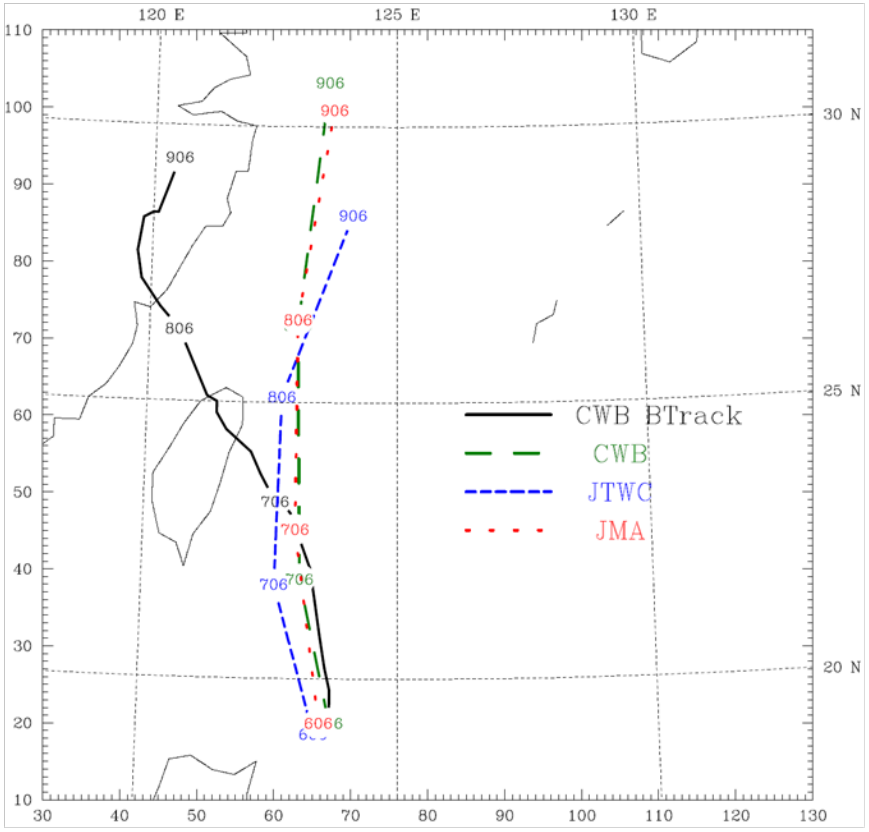
Initial time:2009-10-02-00:00

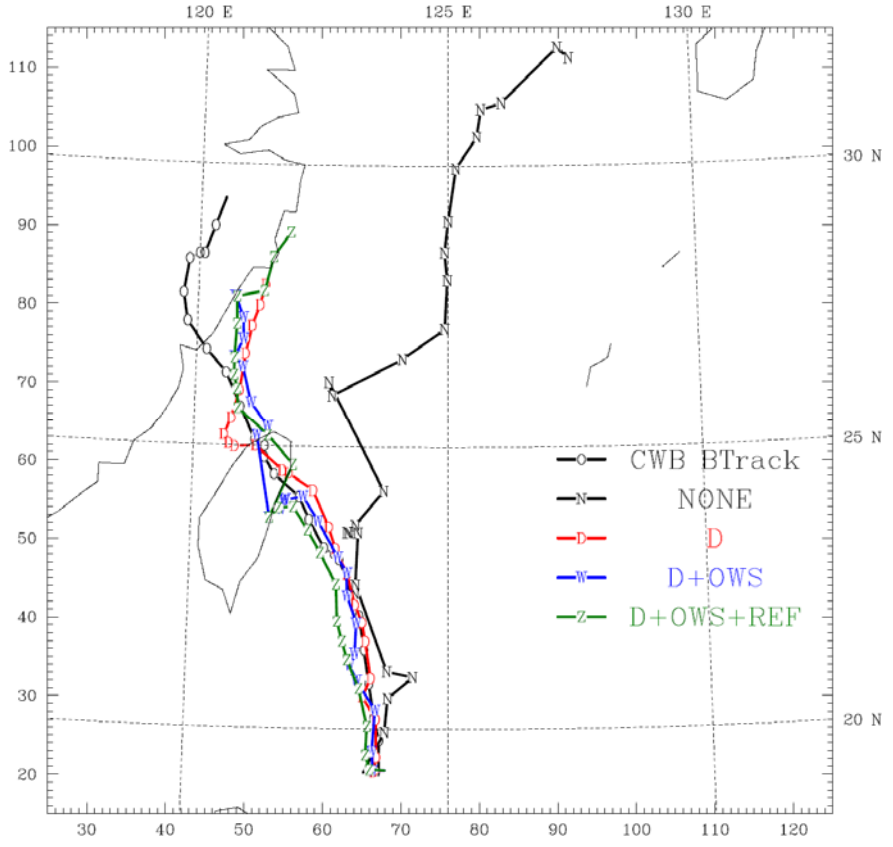






Typhoon Kalmaegi (2008)

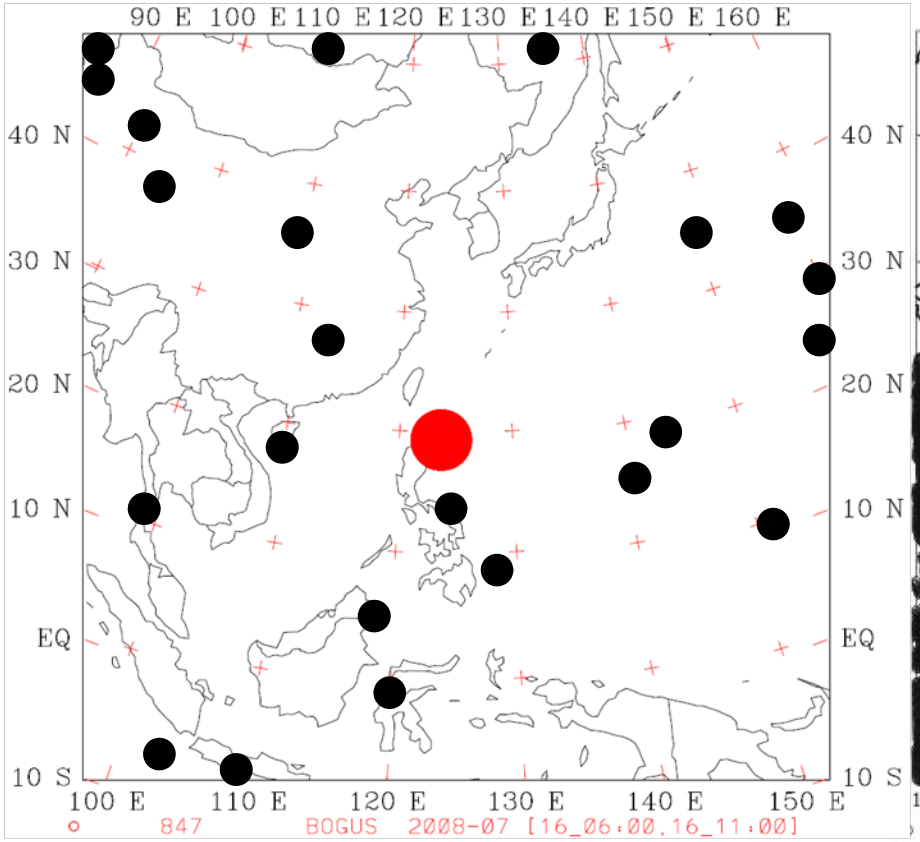




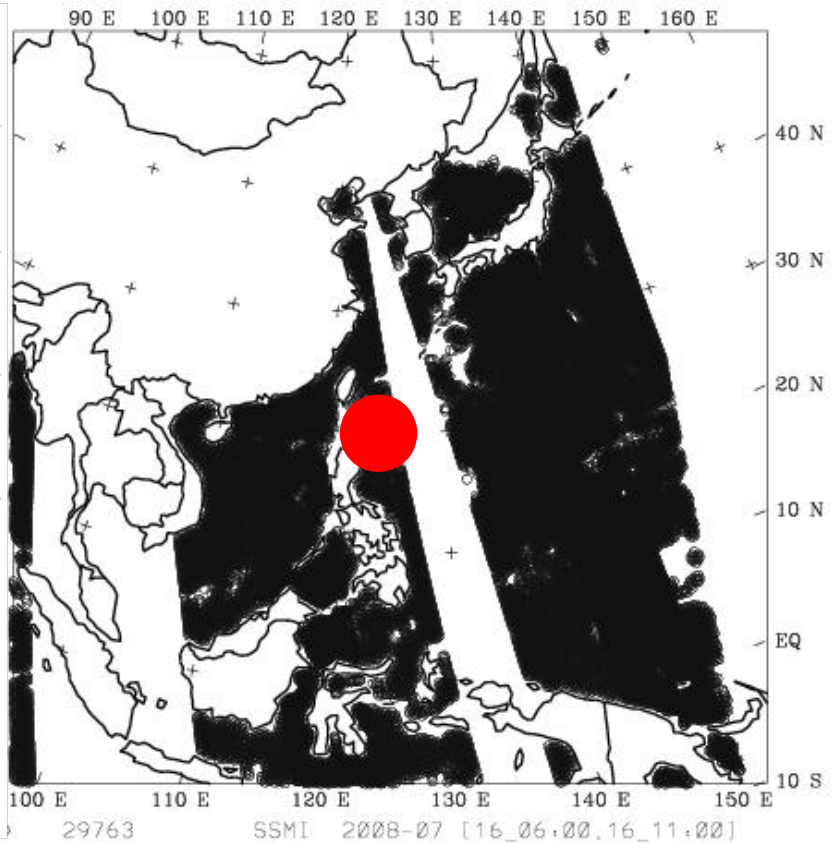
2008/07/16 06Z-07/19 06Z

MM5 V3.7.4 (45-km, 15=km, 5-km)
MM5 4DVAR V3 (BDA in domain-01)
Physics: Simple ice, Grell Cumulus scheme, MRF PBL

COSMIC REF and Bogus



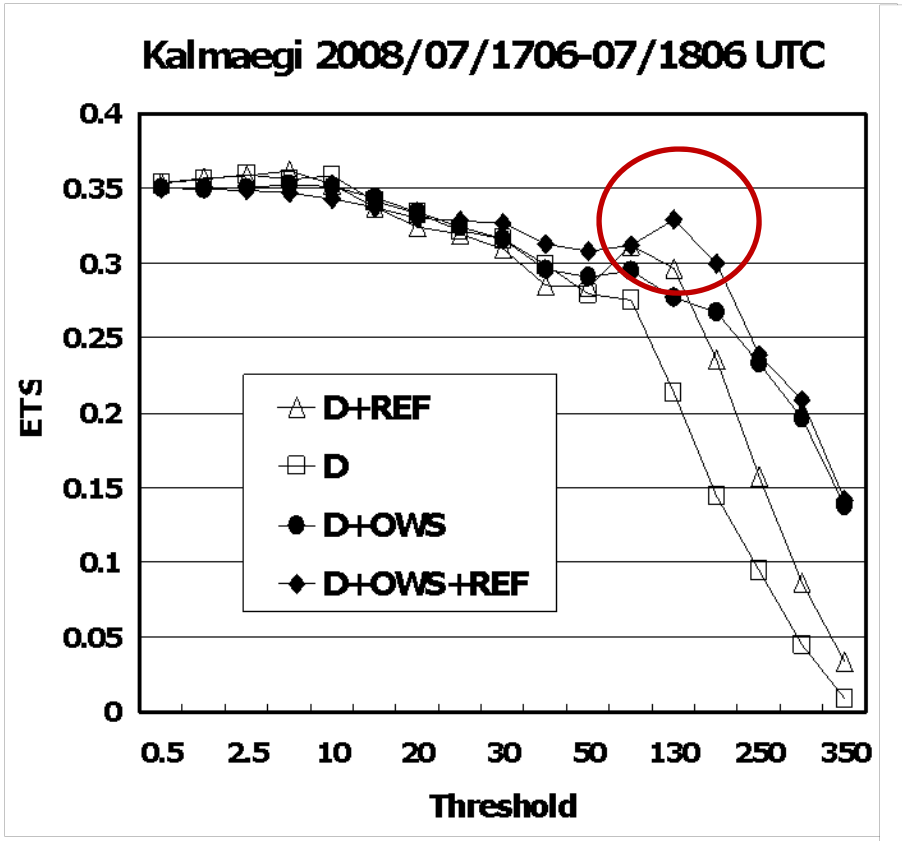
SSM/I OWS and Bogus

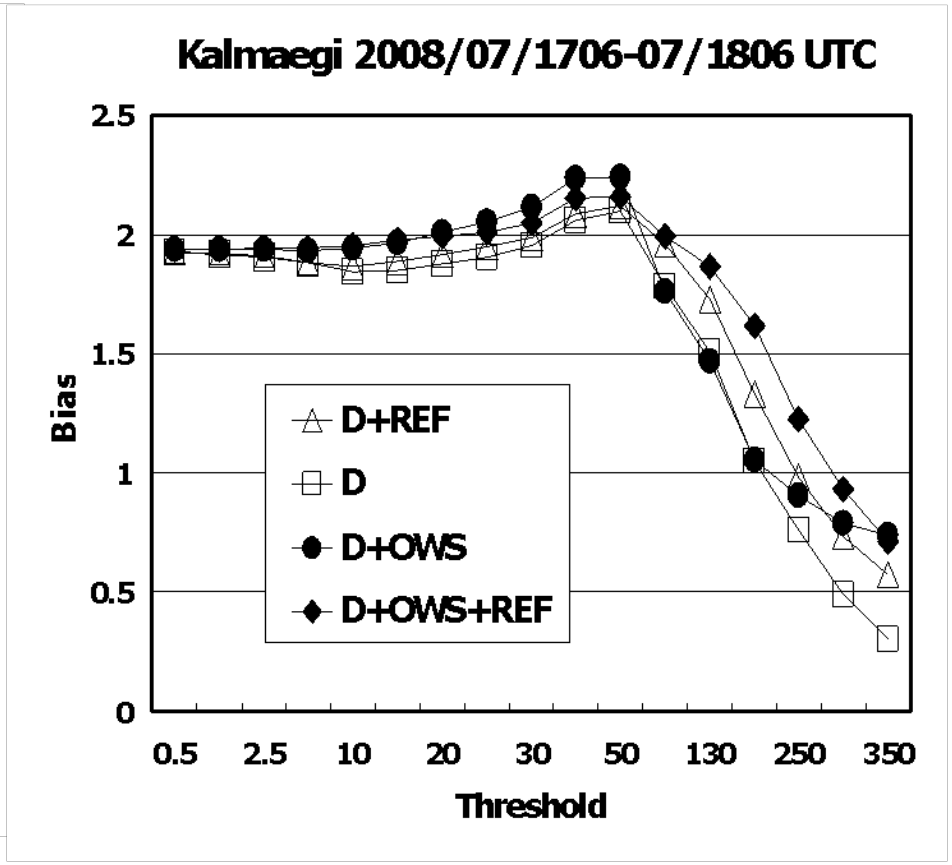


Experiment Framework

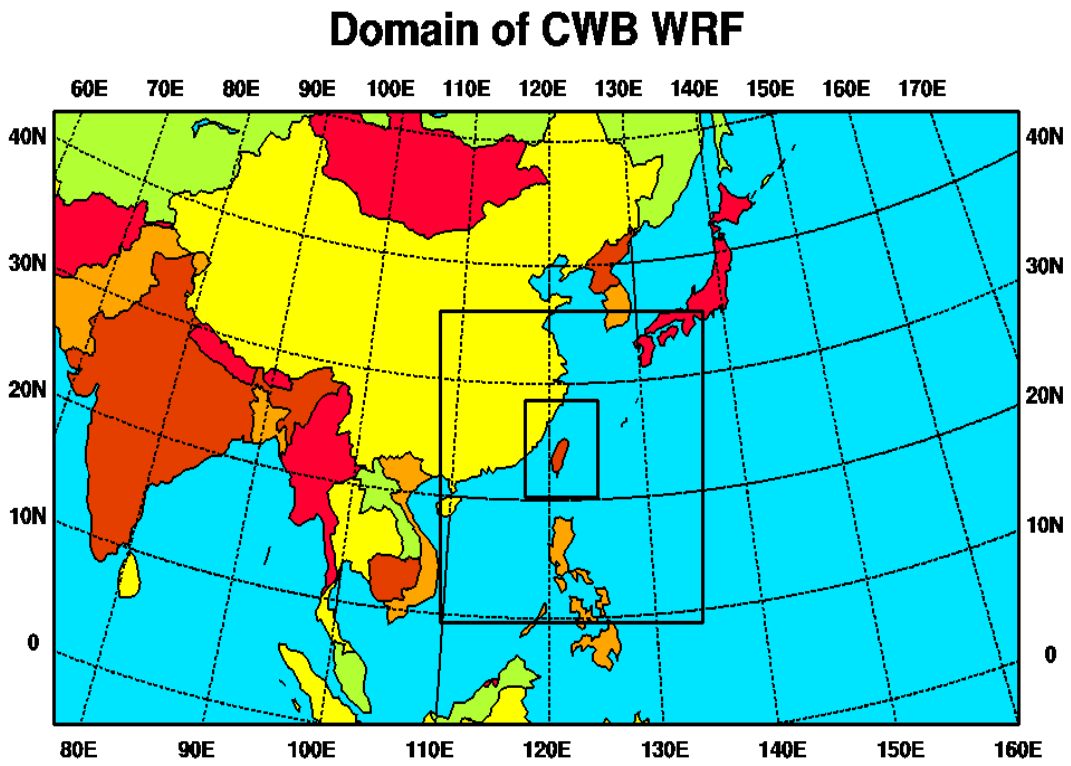
Experiment (3 days Mean Track Error)	Num of obs	Time(HR)	Mean Track Error		
			24	48	72
NONE (292)	-	-	56	245	606
D (136)	847	0-0.5	105	110	209
D+IWV (198)	11139,10426, 4457,5270	1,2,3,4	80	173	362
D+OWS (147)	9982,9774, 4153,5954	1,2,3,4	93	154	210
D+REF (113)	6,2,7,4,4	0,1,2,3,4	97	73	181
D+REF+OWS (99)			91	85	132

Threat Score



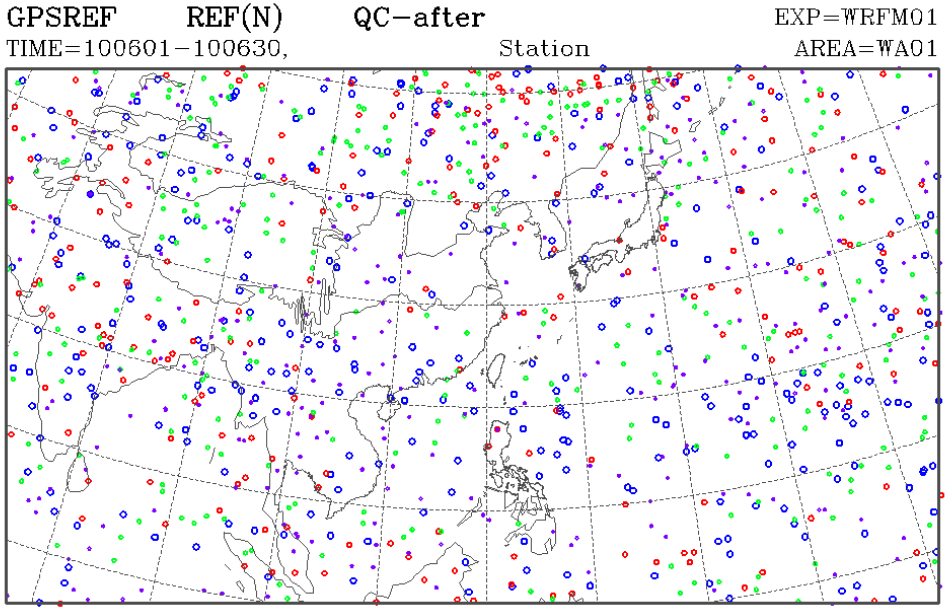


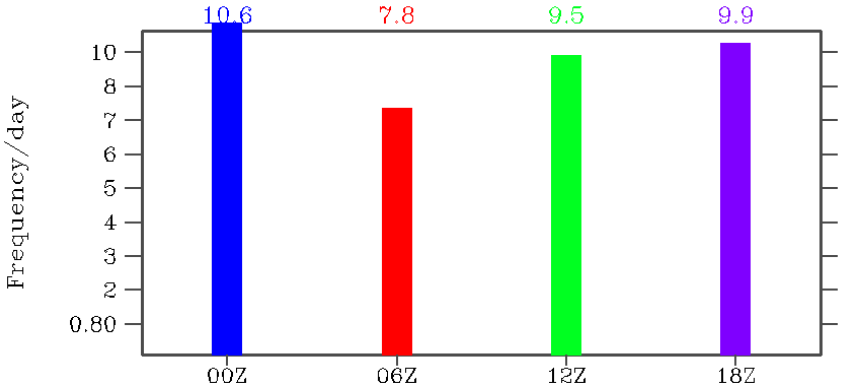
RO data application in CWB-WRF



- WRF-ARW with WRF-Var
- 3 nested domain of 45/15/5 km
- Use WRF-Var inner RO data assimilating technique
  - Assimilate local refractivity

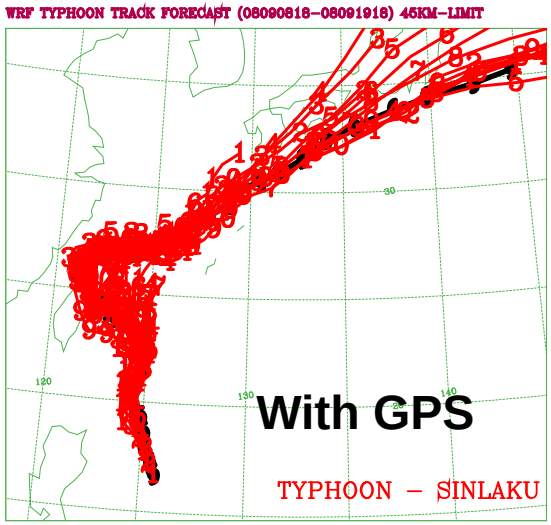
COSMIC RO Data used in CWB-WRF

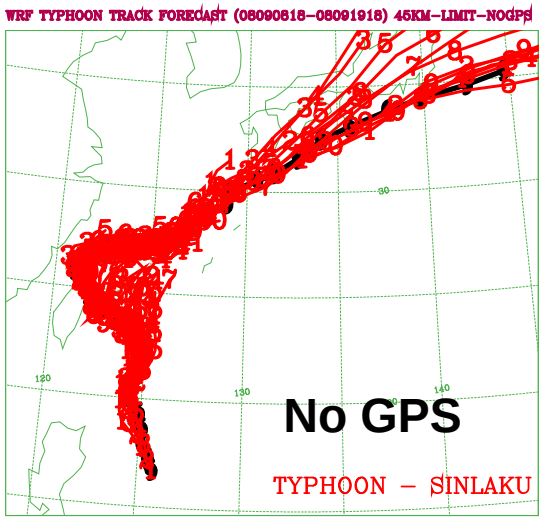


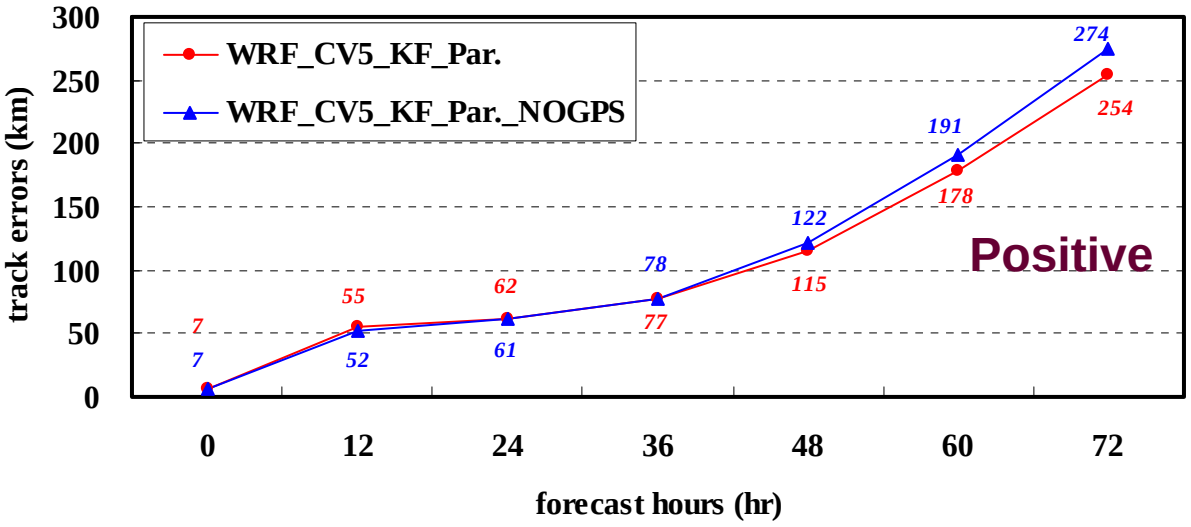


Typhoon Sinlaku (2008)

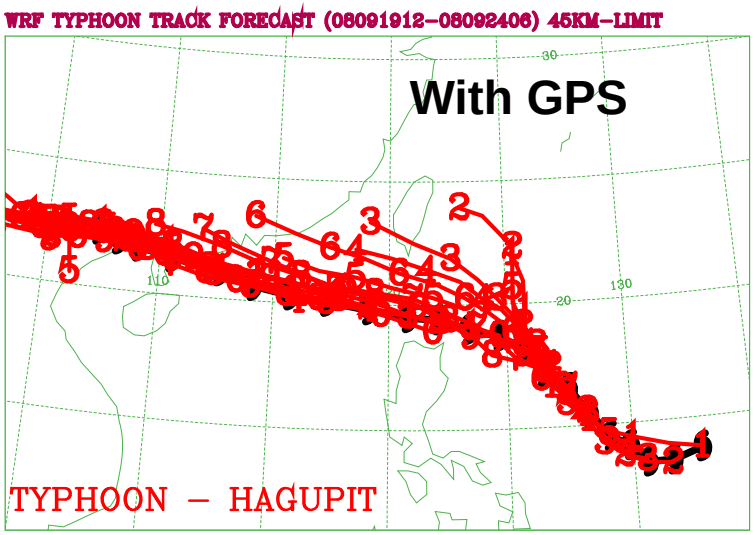
CWB

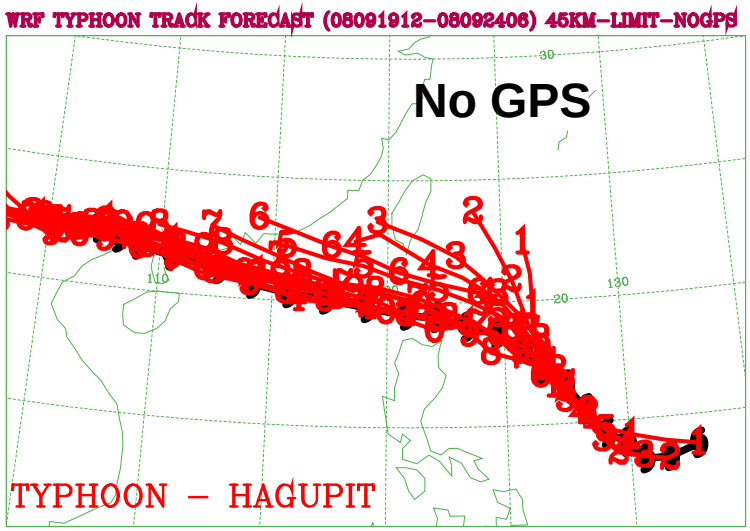


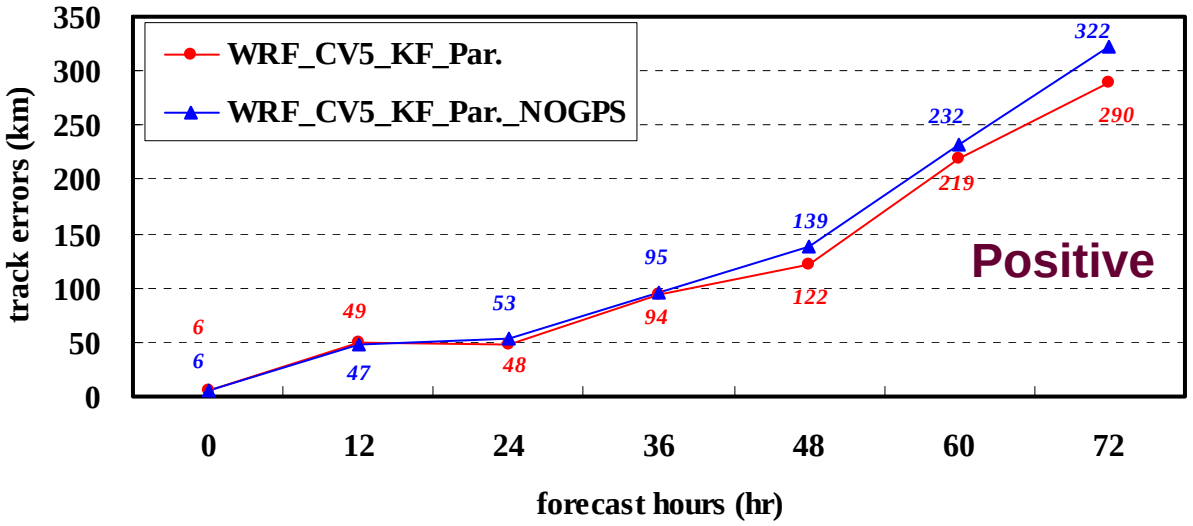




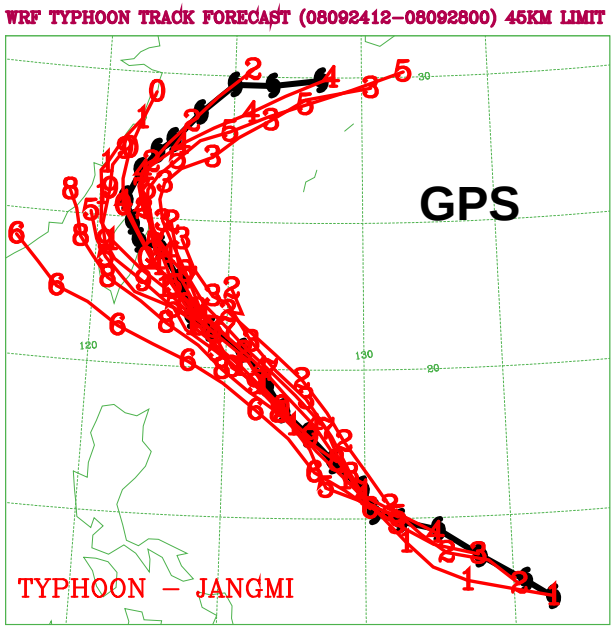
Typhoon Hagupit (2008)

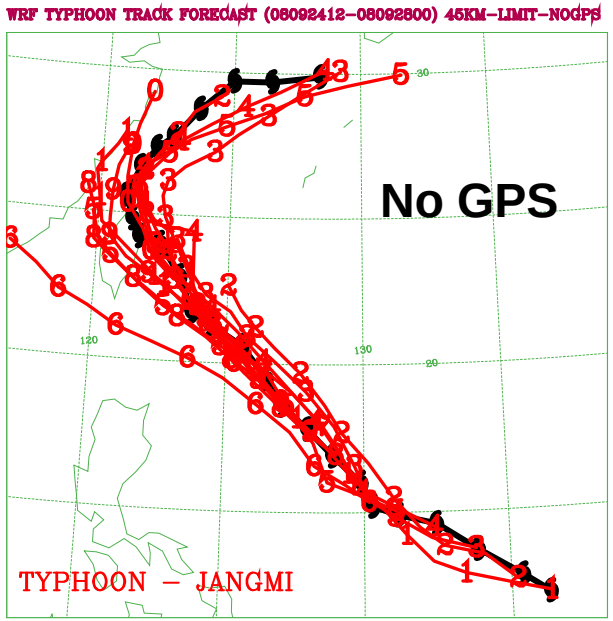


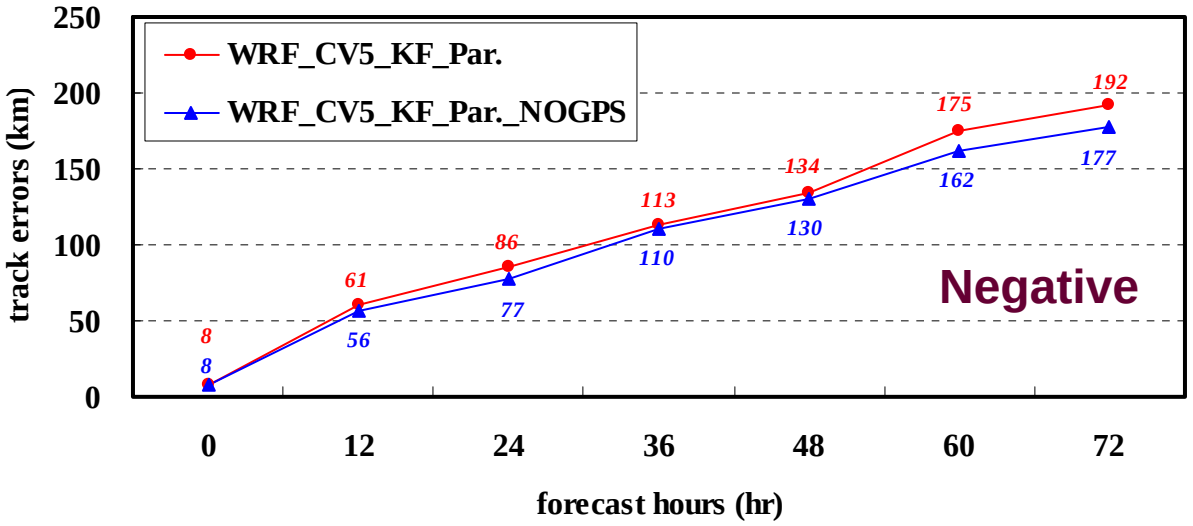




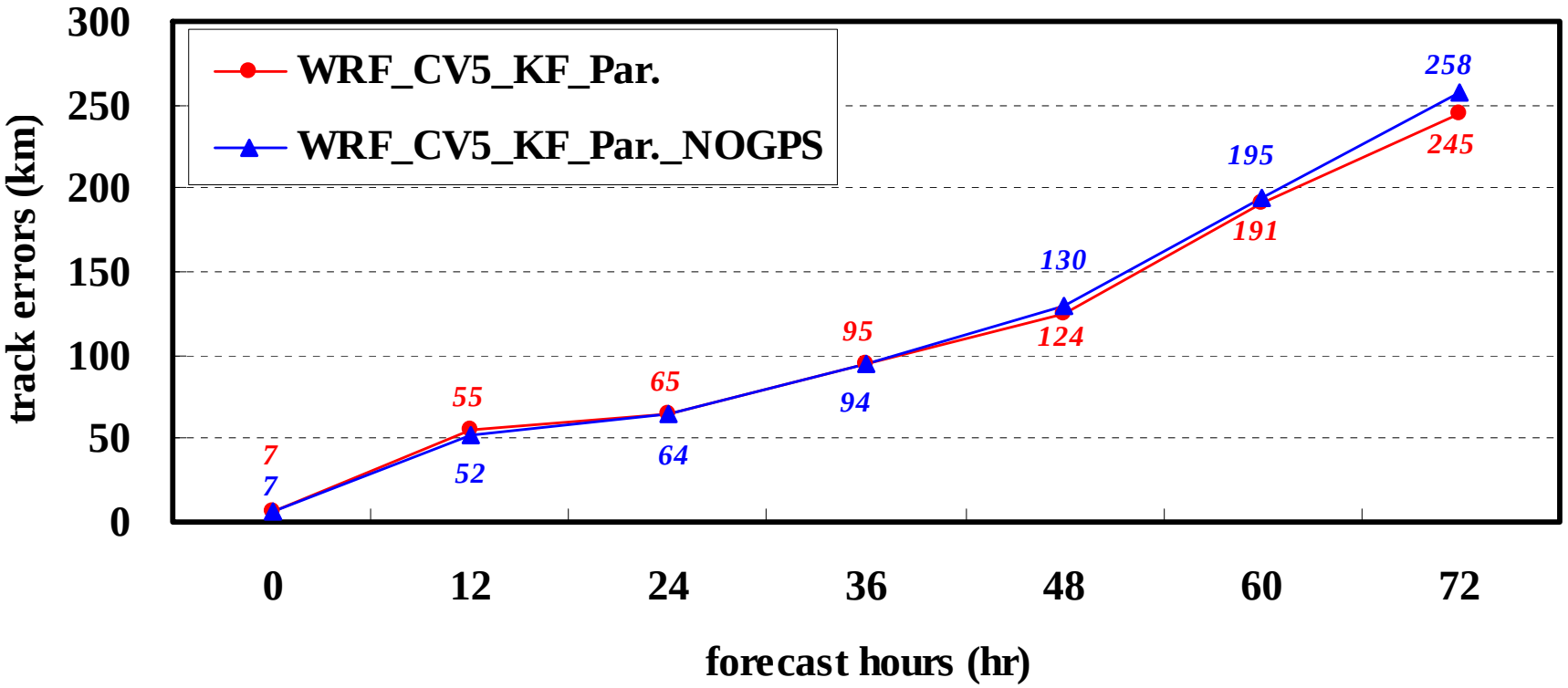
Typhoon Jangmi (2008)





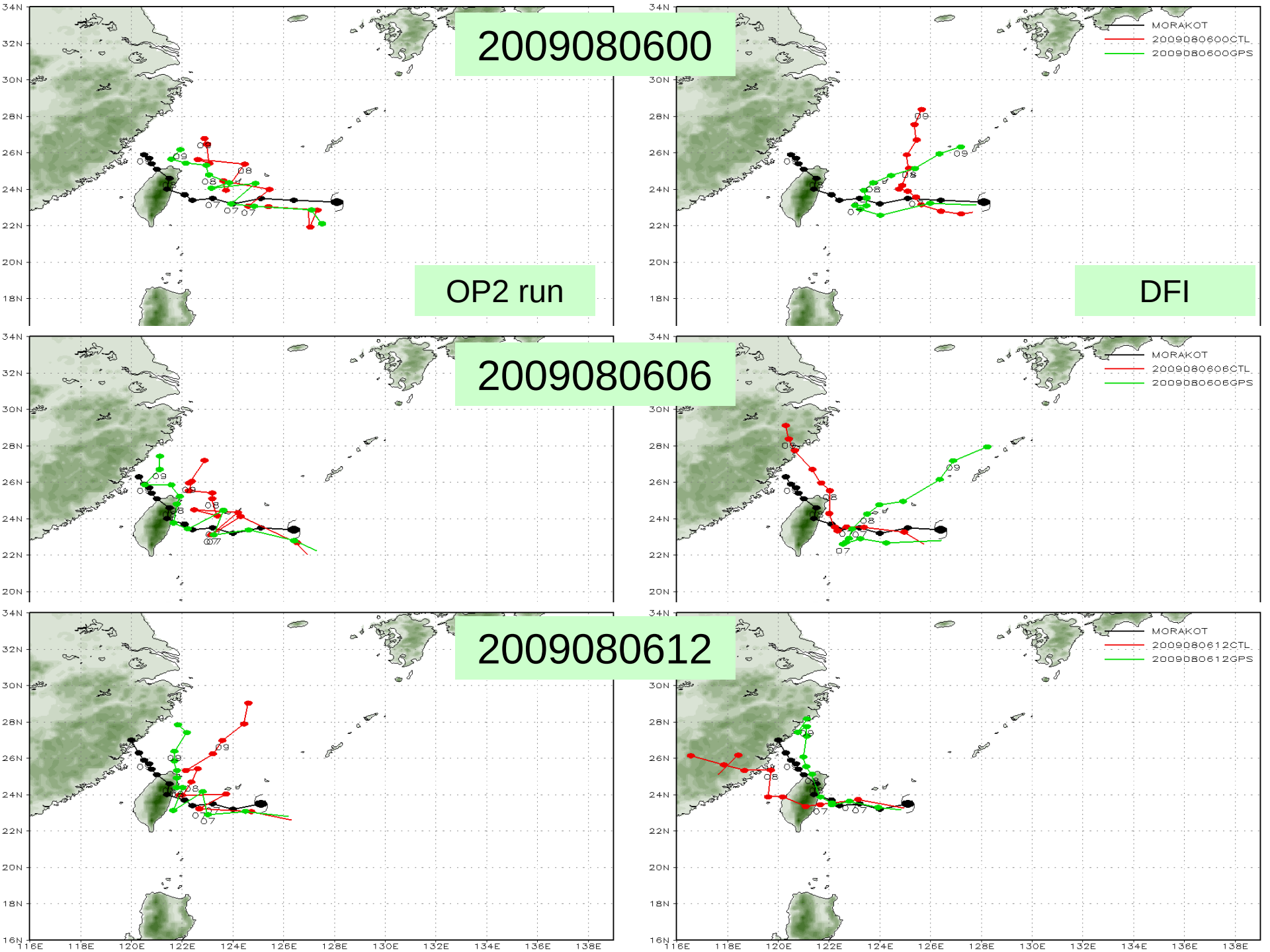


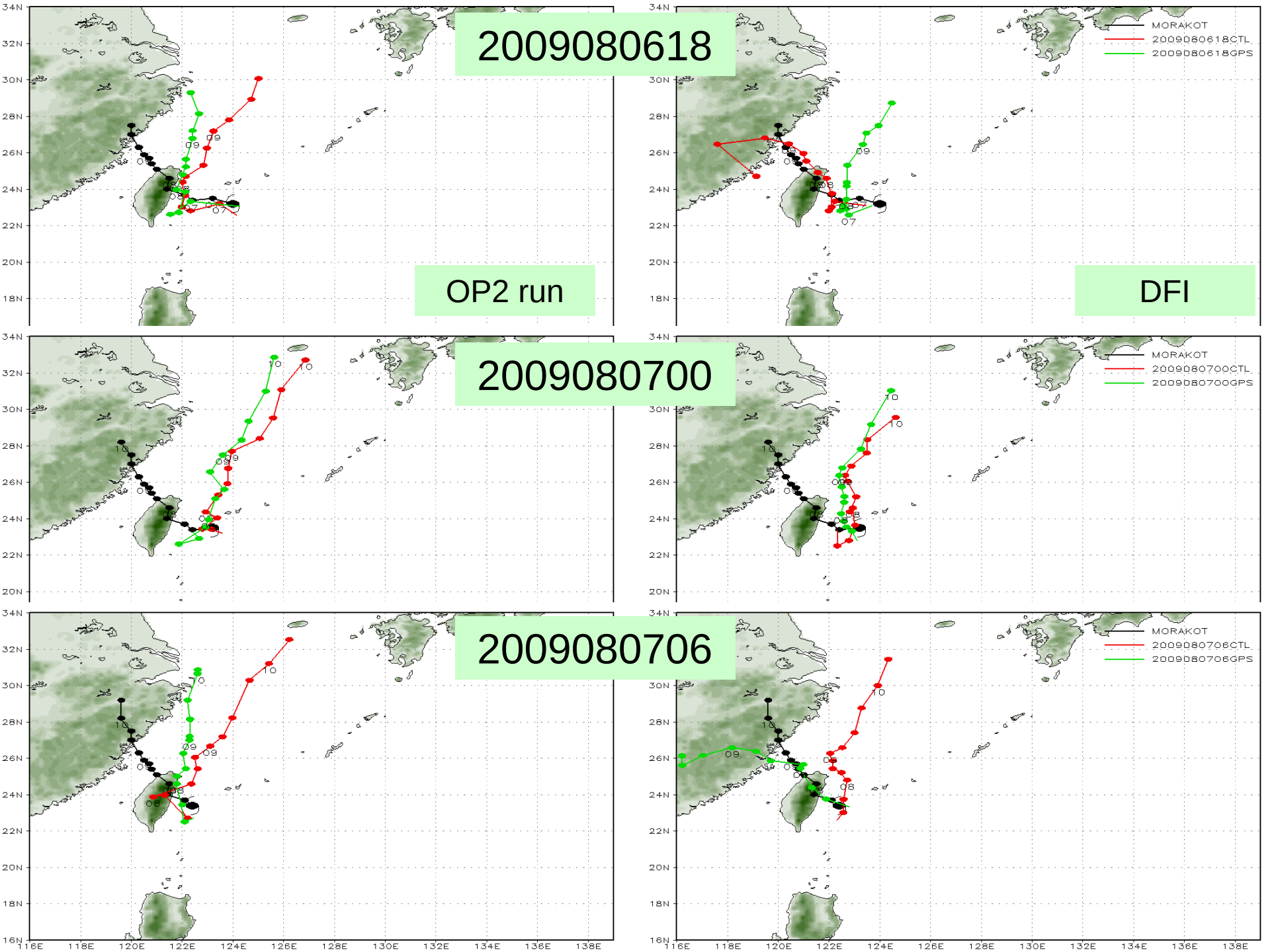
Track Forecast Errors for Sinlaku, Hagupit & Jangmi



Simulation Setup for Morakot

- OP2 run
  - NOGPS
  - GPS
- Relocation+BOGUS_v13+DFI
  - NOGPS
  - GPS
- Run Time： 2009080300~2009080918
- Comparison：2009080318~2009080918


2009080600
OP2 run
DFI
2009080606
2009080612
MORAKOT
2009080600CTL
2009080600GPS
2009080606CTL
2009080606GPS
2009080612CTL
2009080612GPS

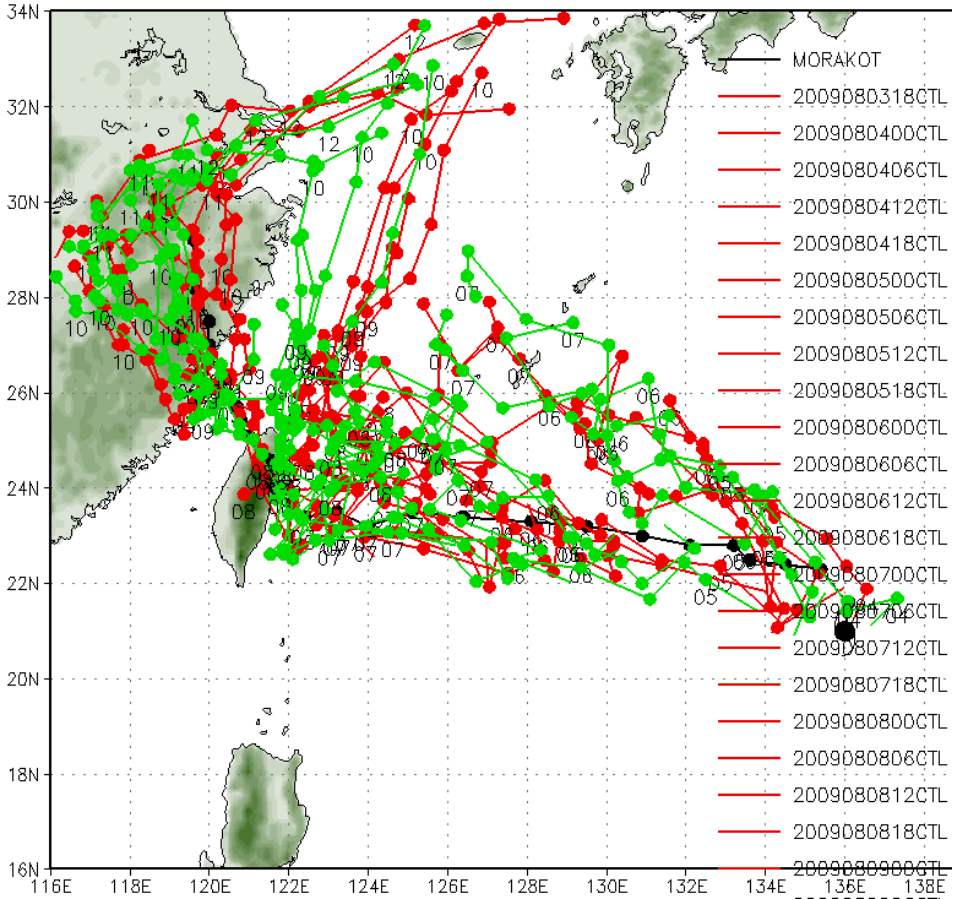

2009080618
OP2 run
DFI
MORAKOT
2009080618CTL
2009080618GPS
2009080700
MORAKOT
2009080700CTL
2009080700GPS
2009080706
MORAKOT
2009080706CTL
2009080706GPS

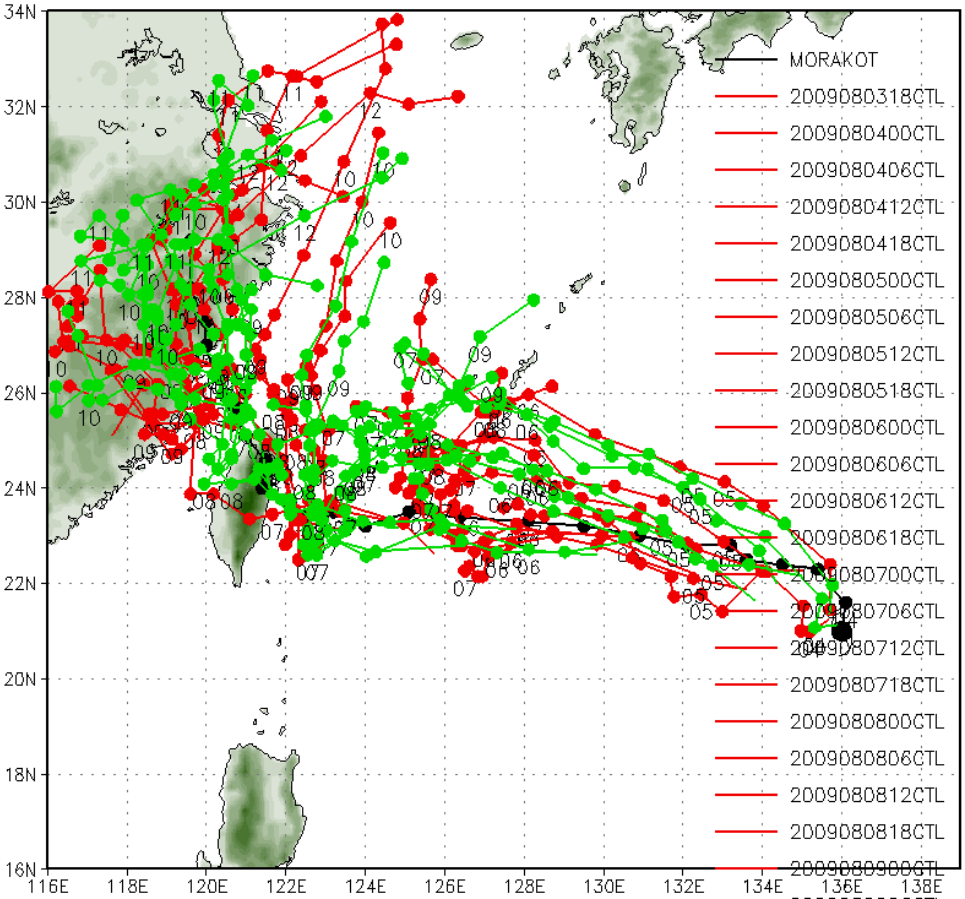
Evaluating the impact of COSMIC GPS RO data on the prediction of Typhoon Morakot, using the CWB 45-km operational WRF system (OP2) and the another system with digital filter, from 080318 – 080918 (a week long period).

Red: No GPS, Green: With GPS

OP2 run

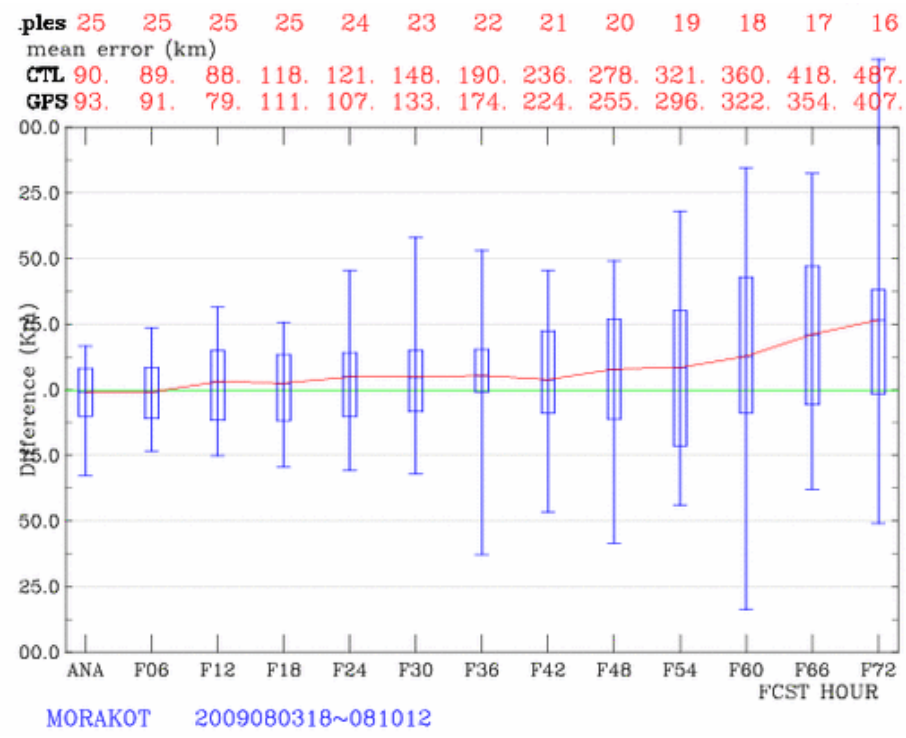
DFI



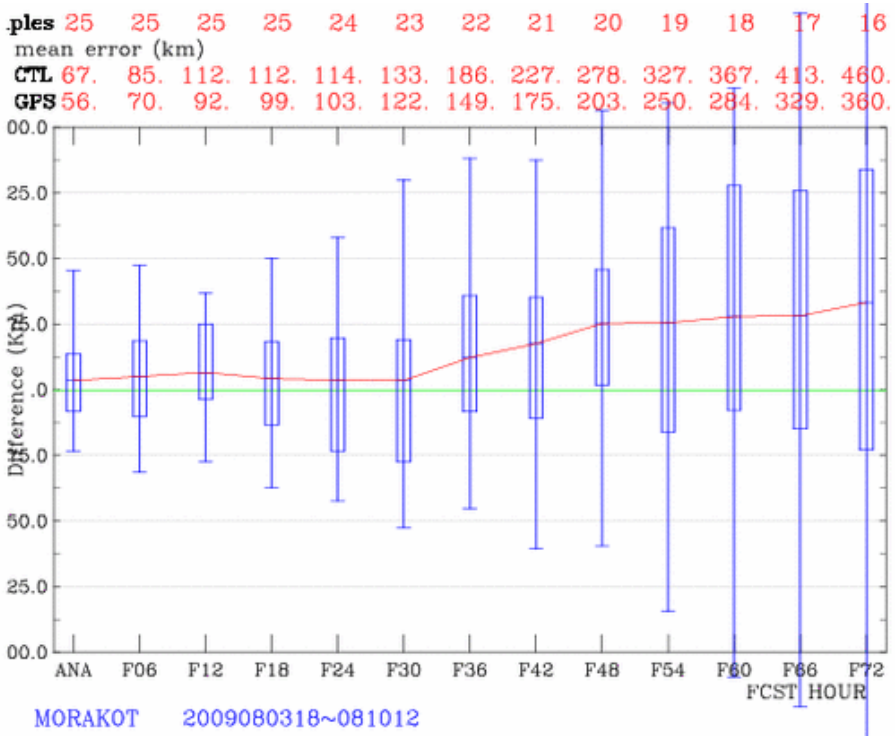


GPS RO is shown to have an impact on typhoon track prediction, particularly, after 36-h. The impact is even more robust with the use of digital filter initialization.

OP2 run



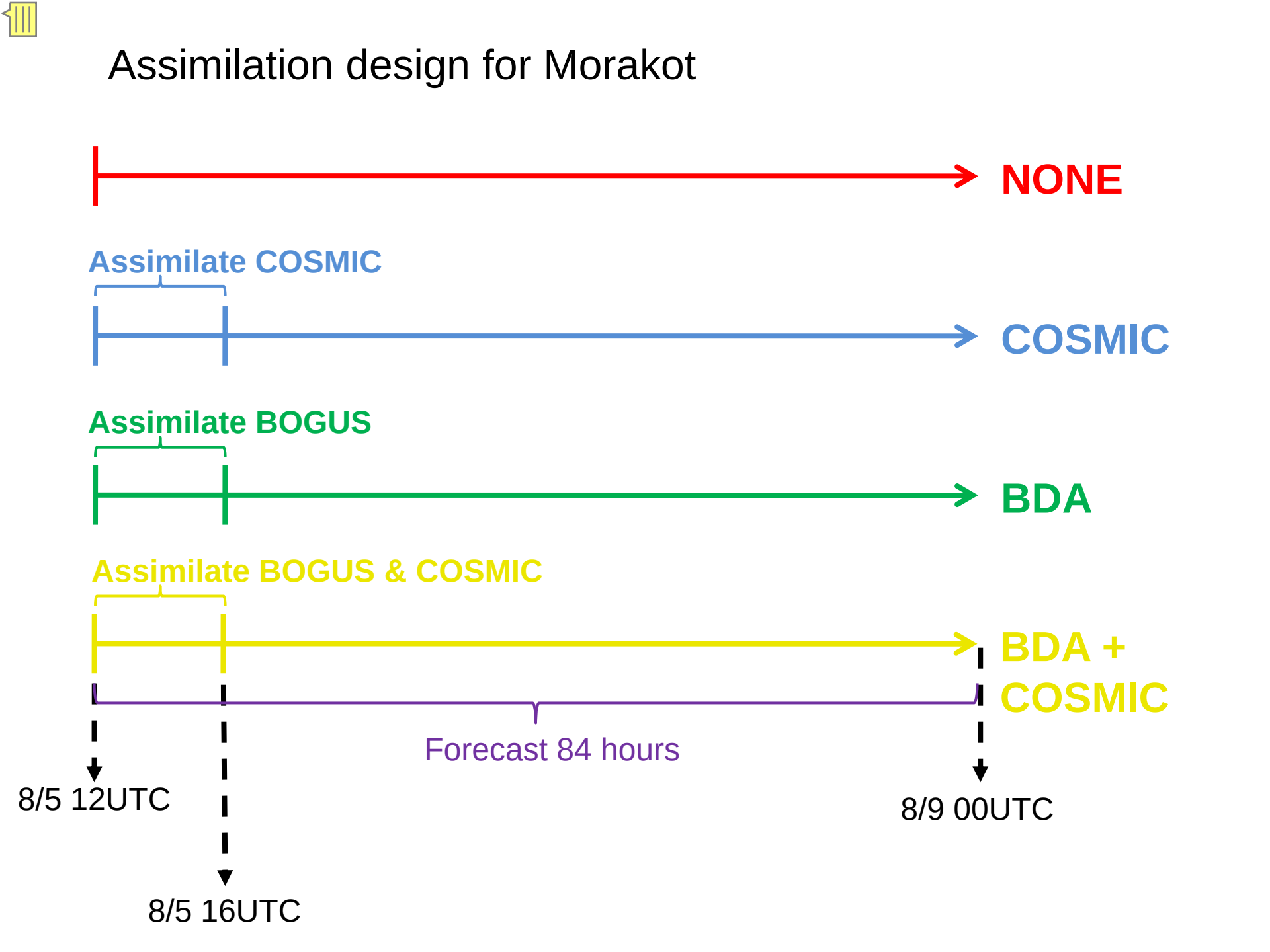
DFI



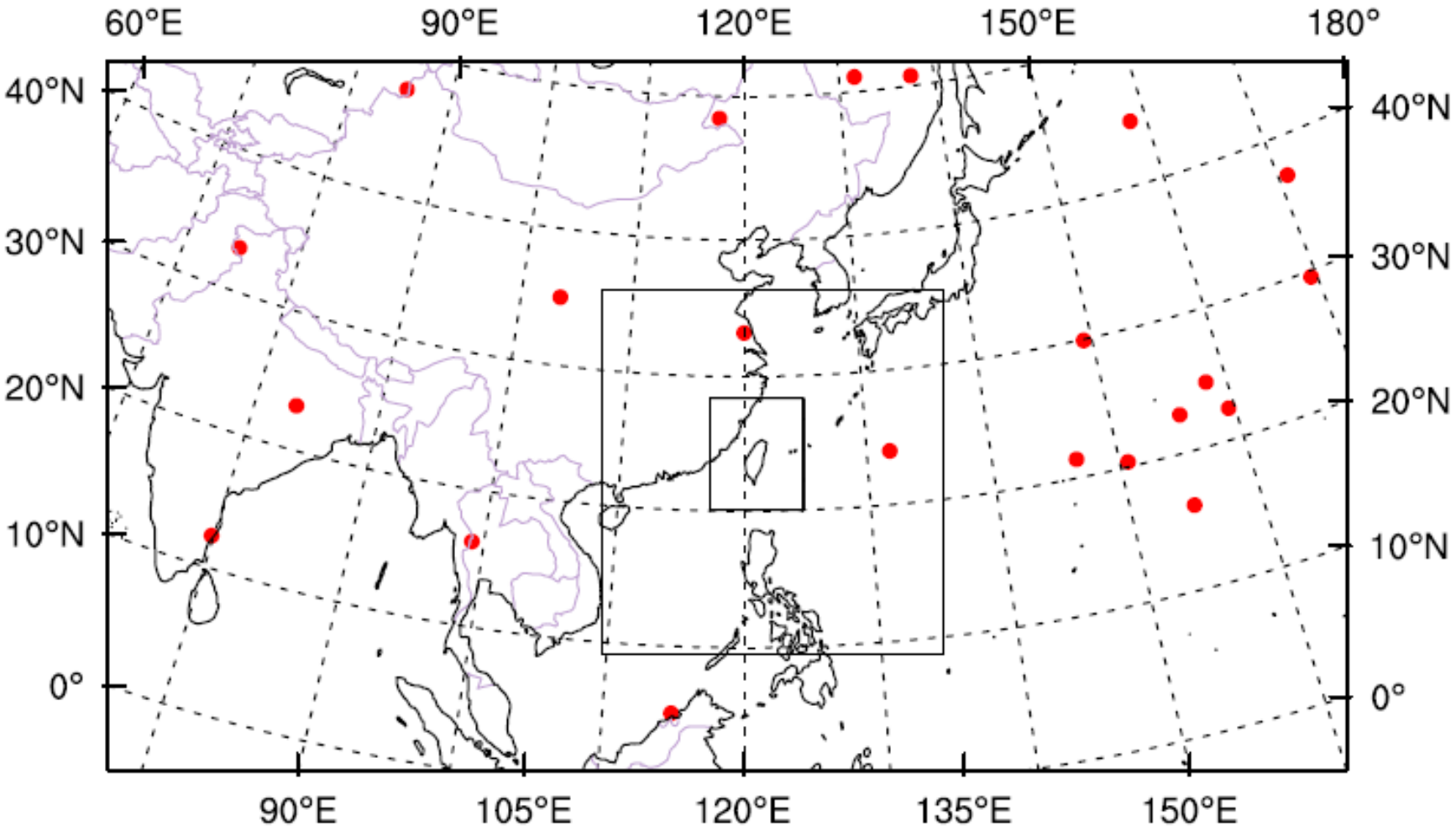
diff-=CTL-GPS

Positive means improvement from assimilating GPSRO

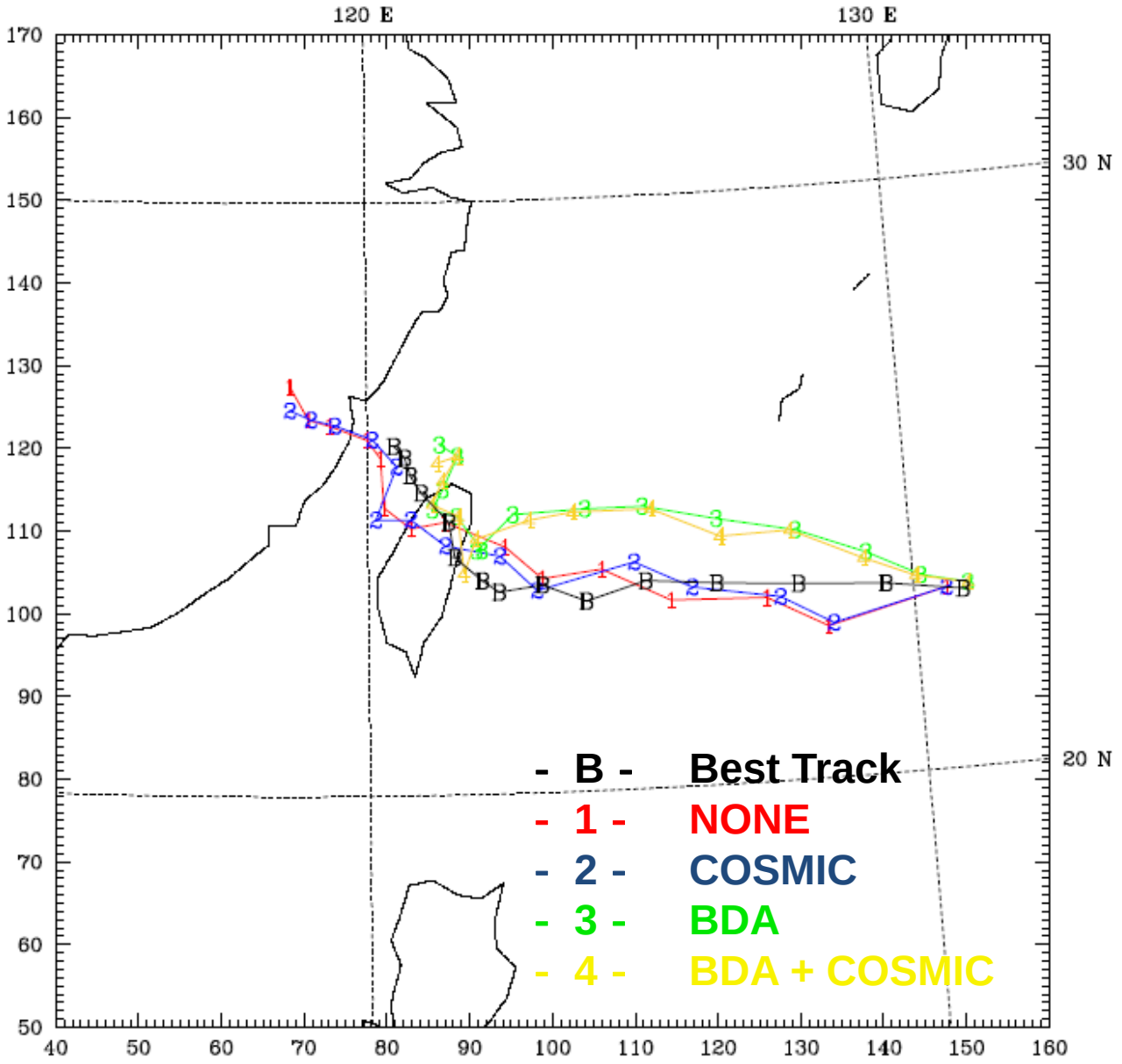
Assimilation design for Morakot

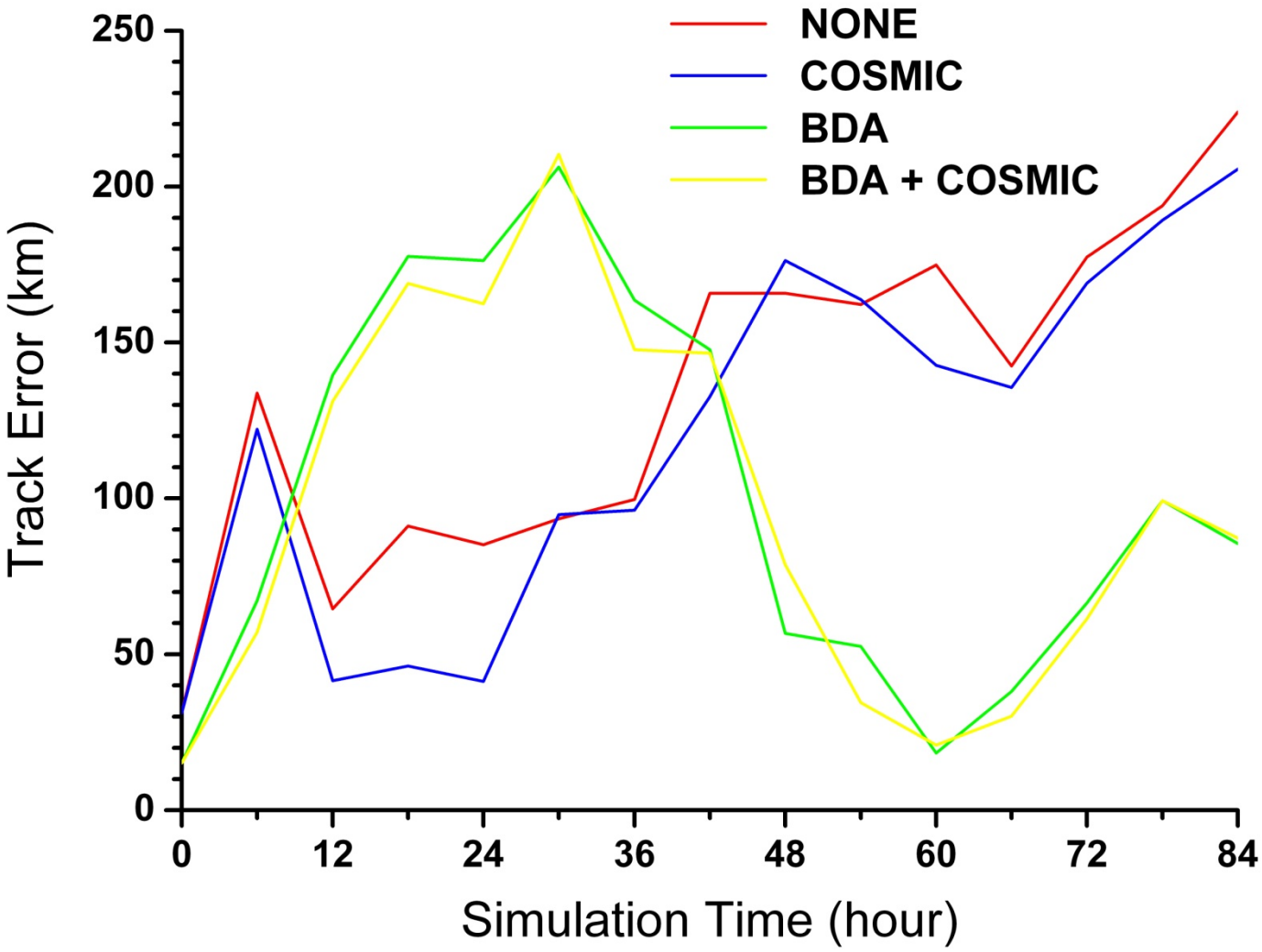


GPS RO 2009/08/05 12UTC - 2009/08/05 16UTC



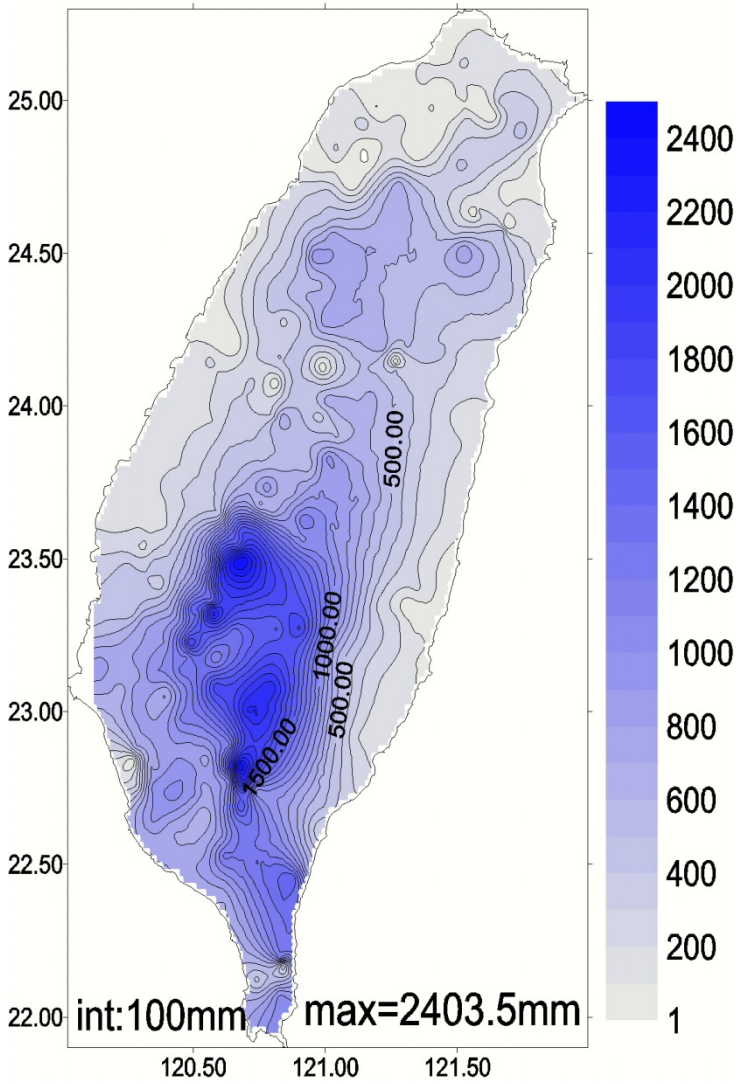
	Domain 1	Domain 2	Domain 3
No. of Occultations	22	2	0

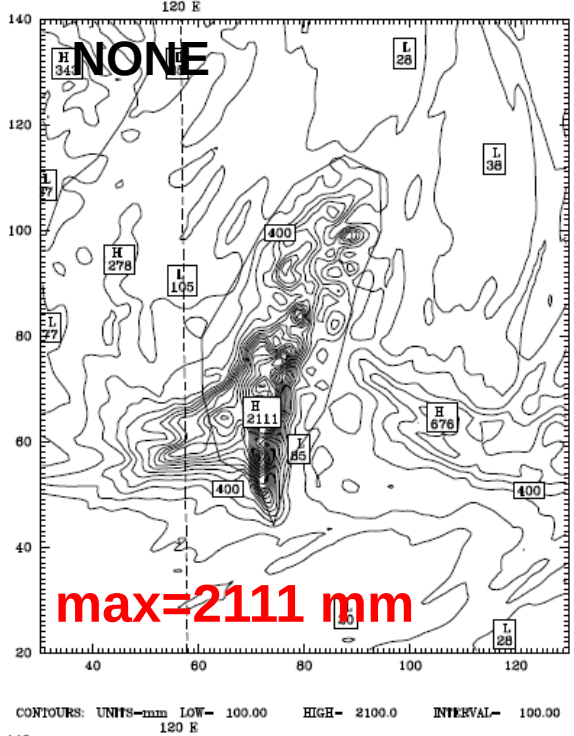

120 E
130 E
30 N
20 N
- B - Best Track
- 1 - NONE
- 2 - COSMIC
- 3 - BDA
- 4 - BDA + COSMIC

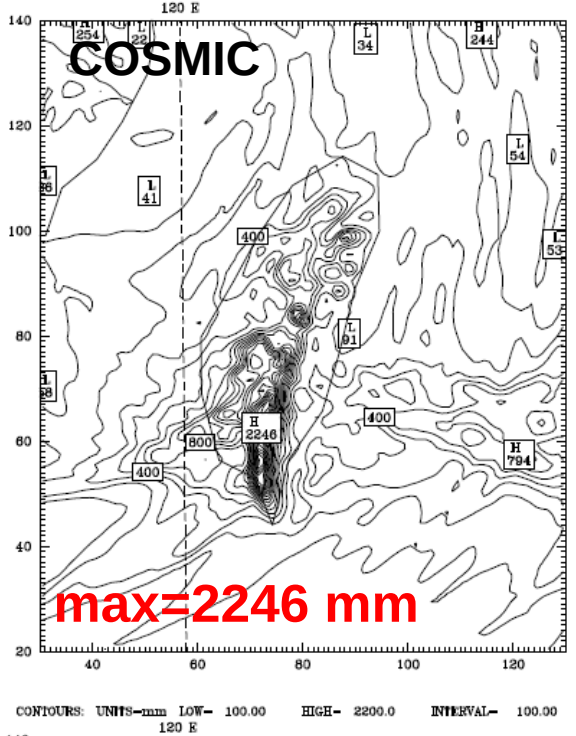


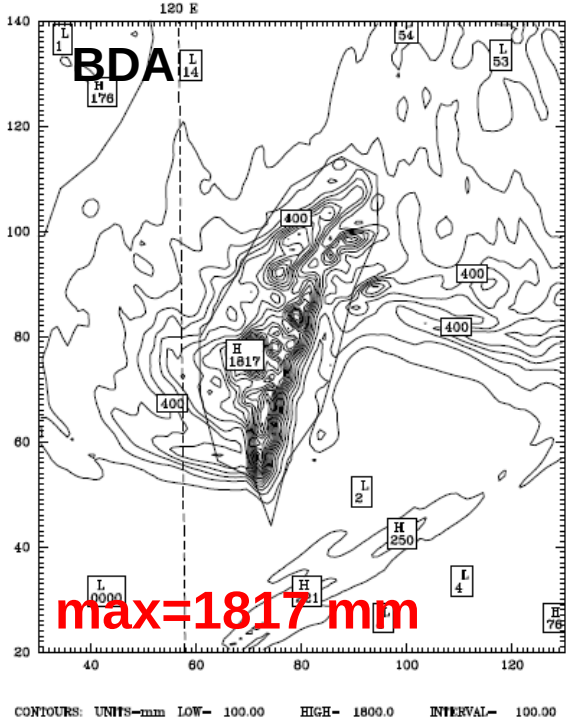
Experiment	NONE	COSMIC	BDA	BDA + COSMIC
Mean Track Error (km)	134	119	101	97

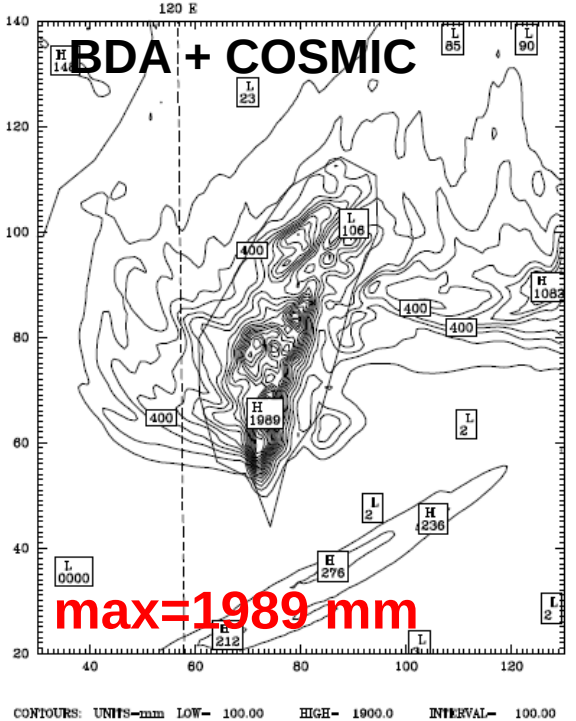
Morakot rainfall



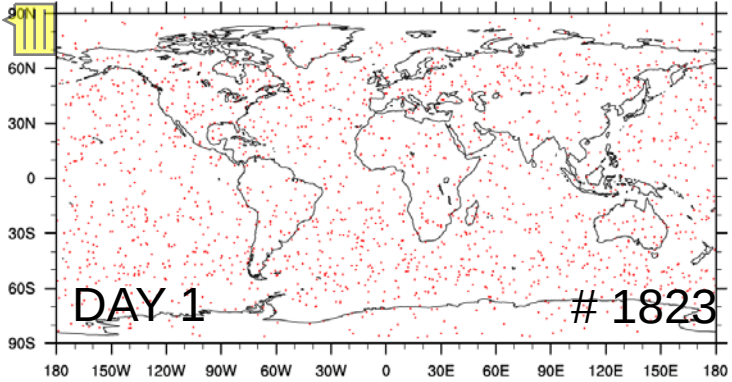


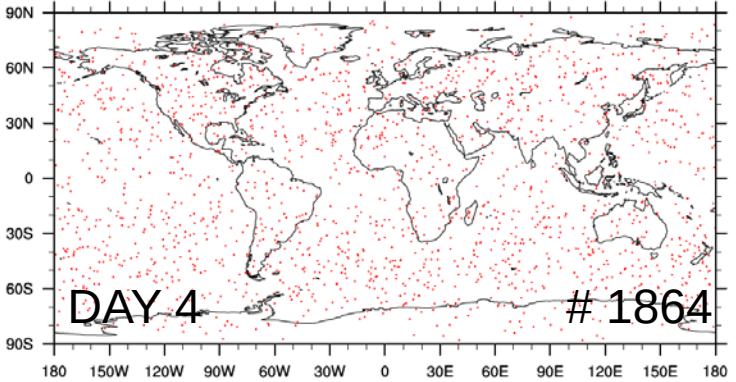


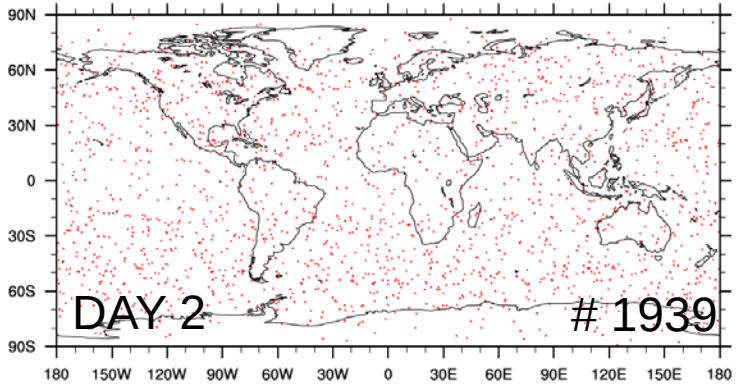


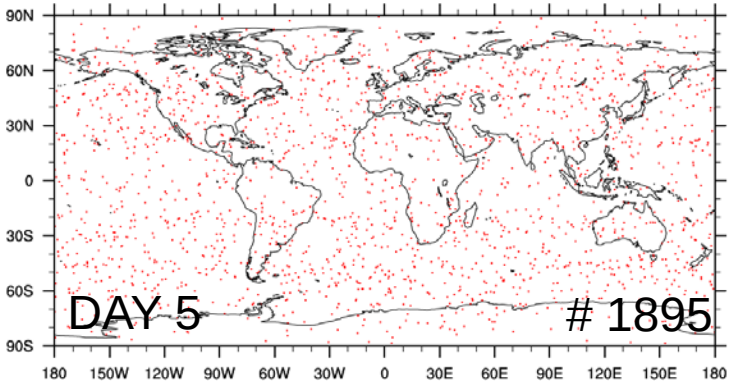


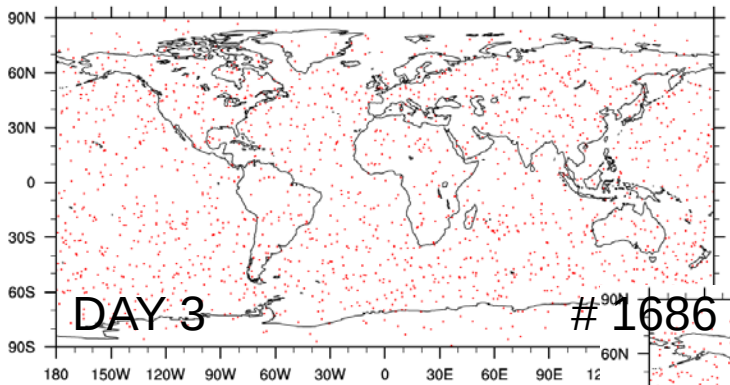
COSMIC
(8/5 ~ 8/11)

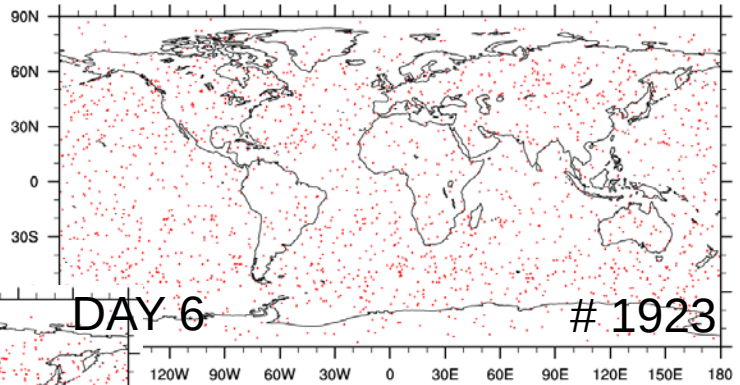


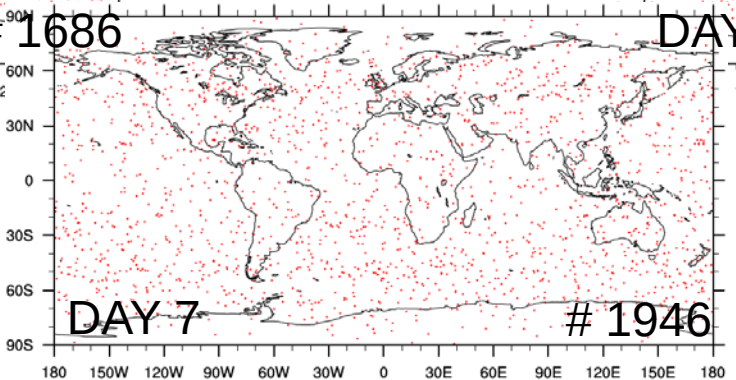






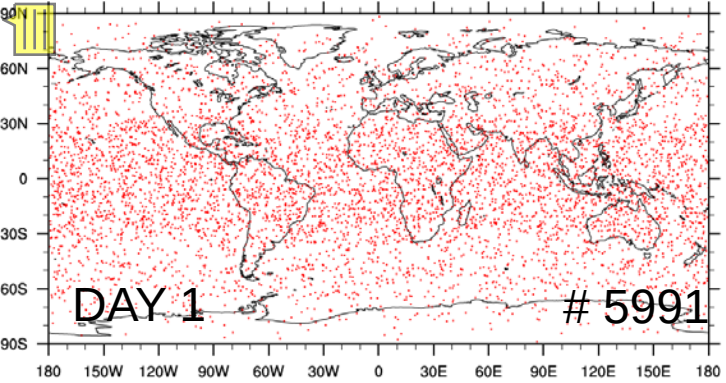


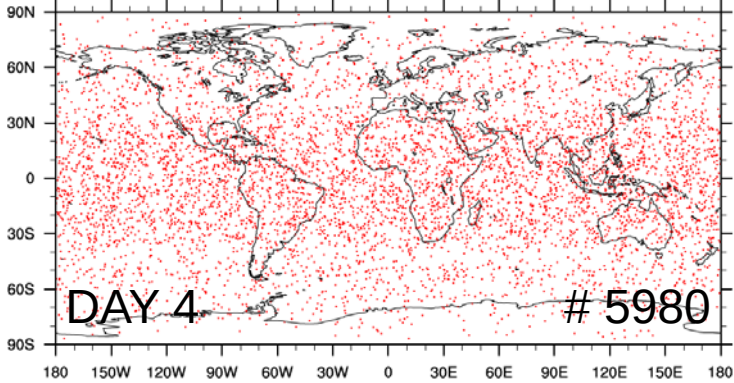


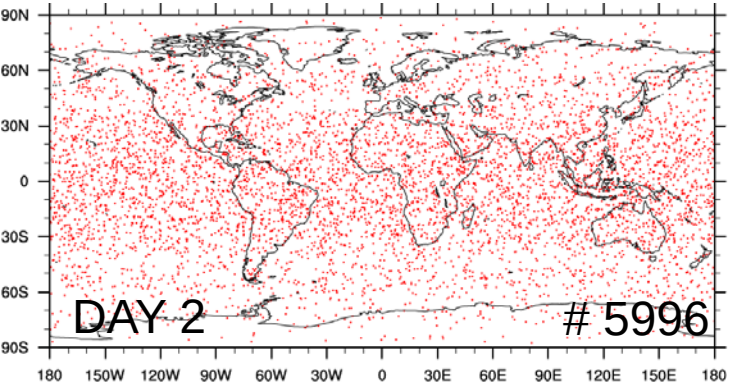


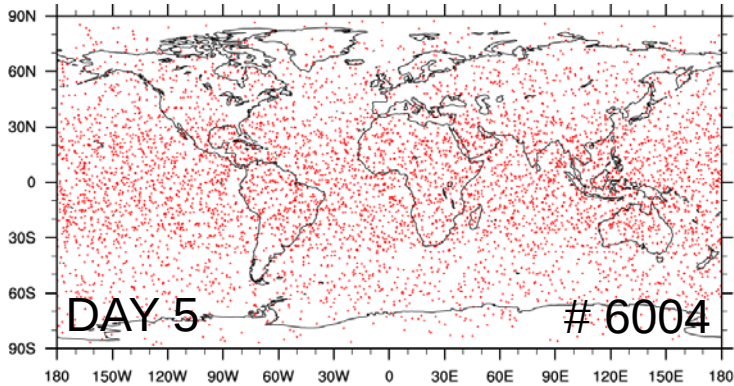
COSMIC-II
(DAY1 ~ 7)
6/72º
6/24º

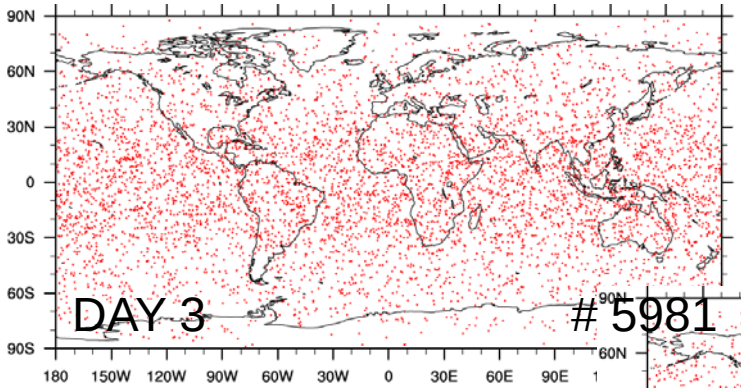
From NSPO

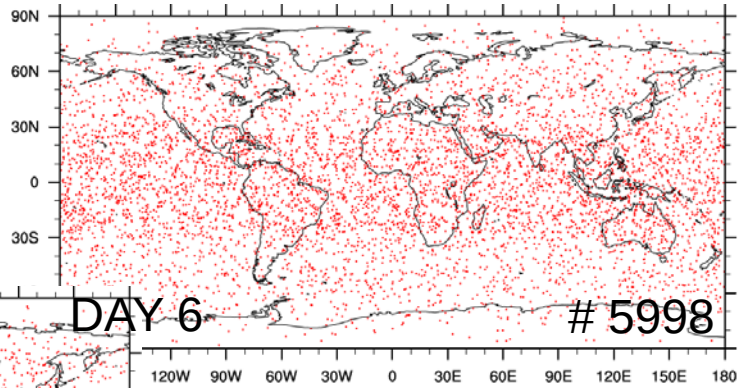


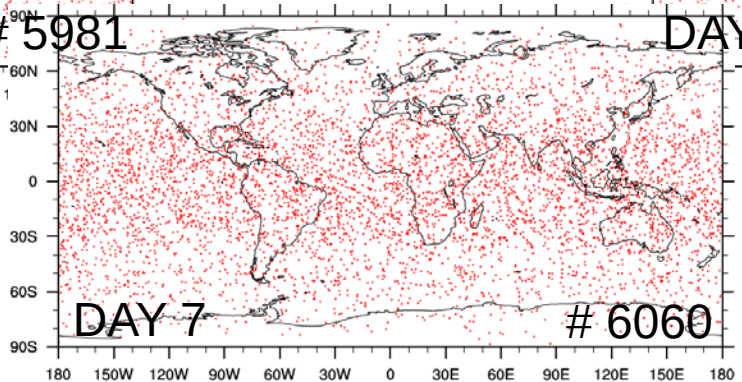




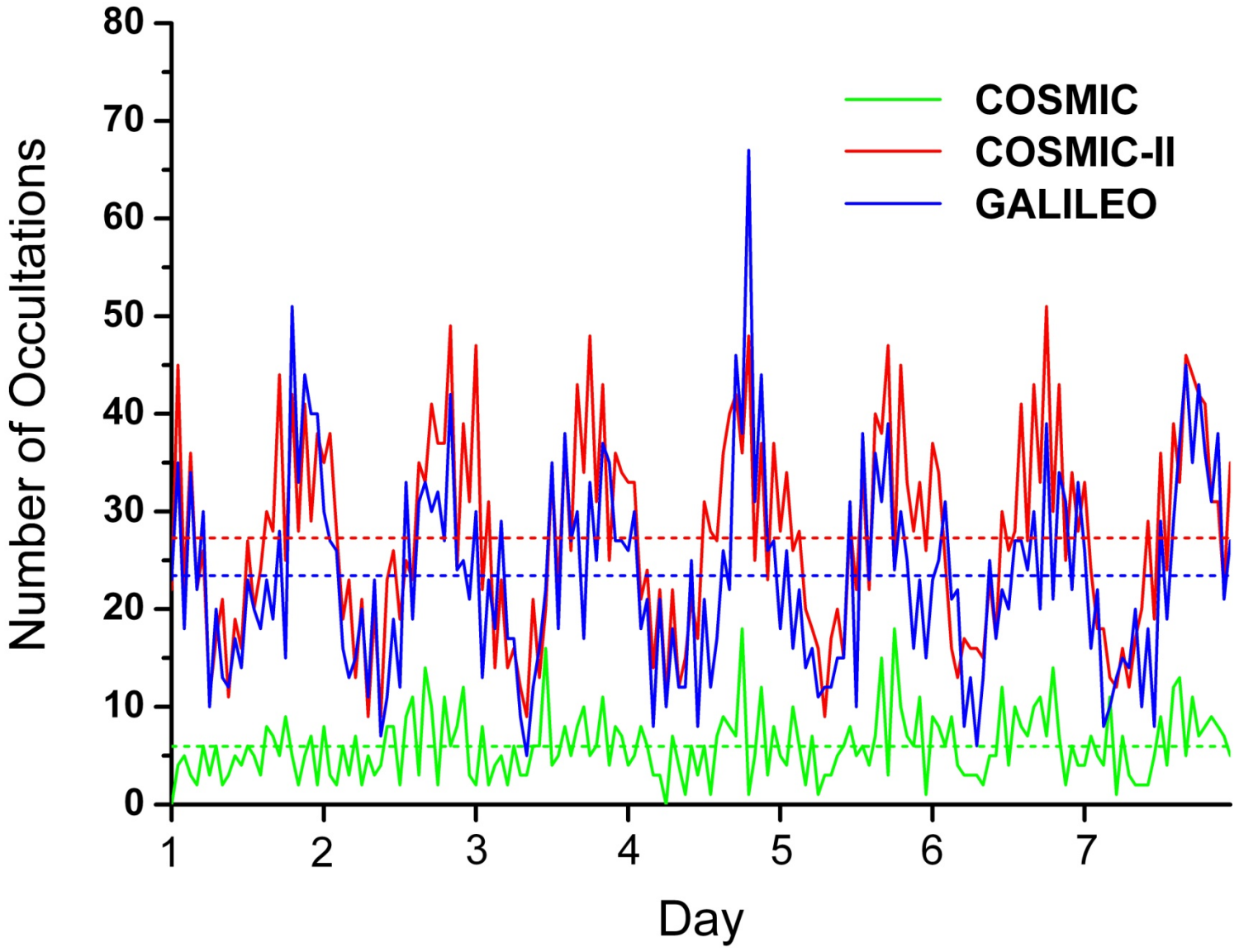




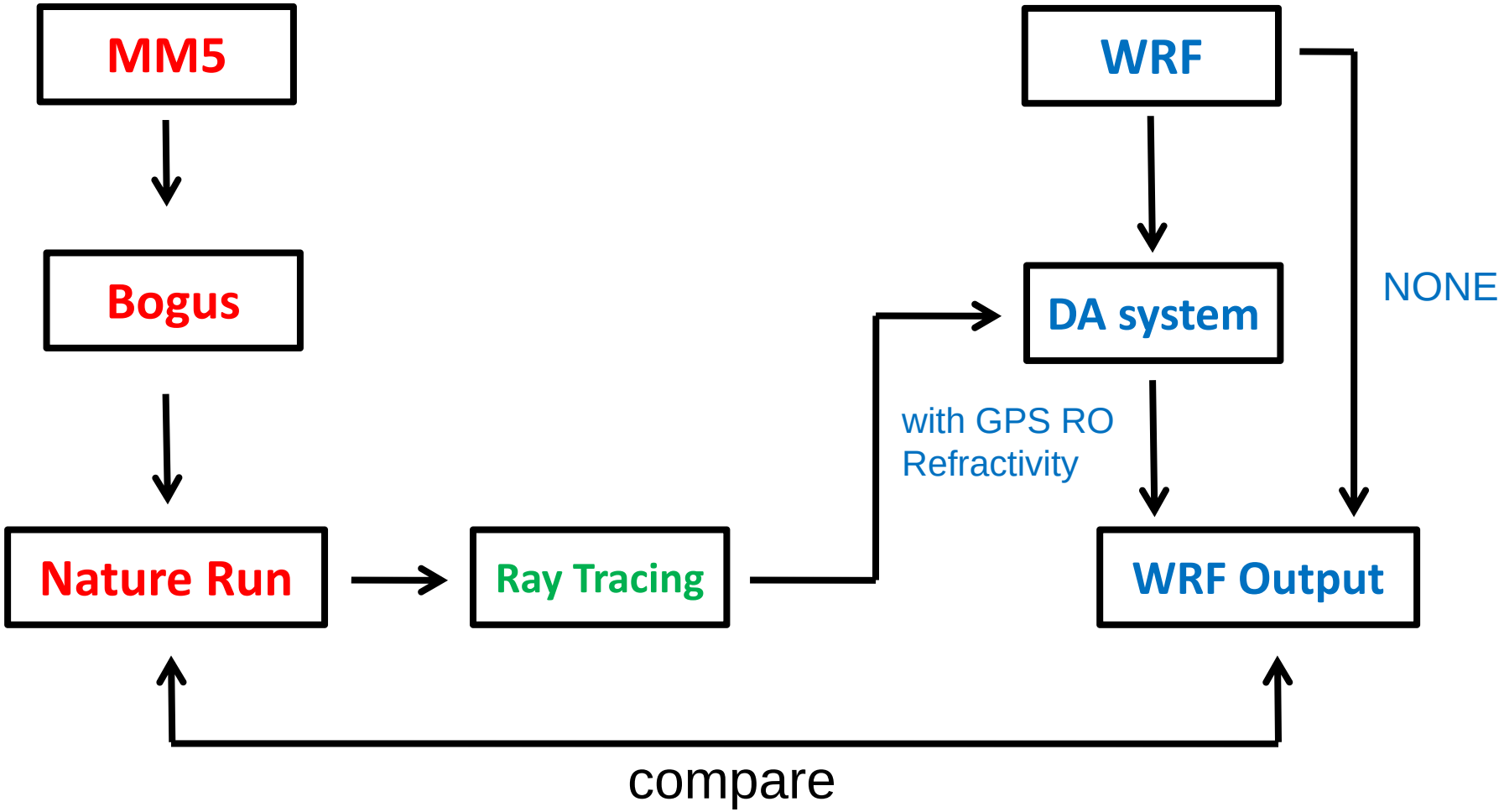




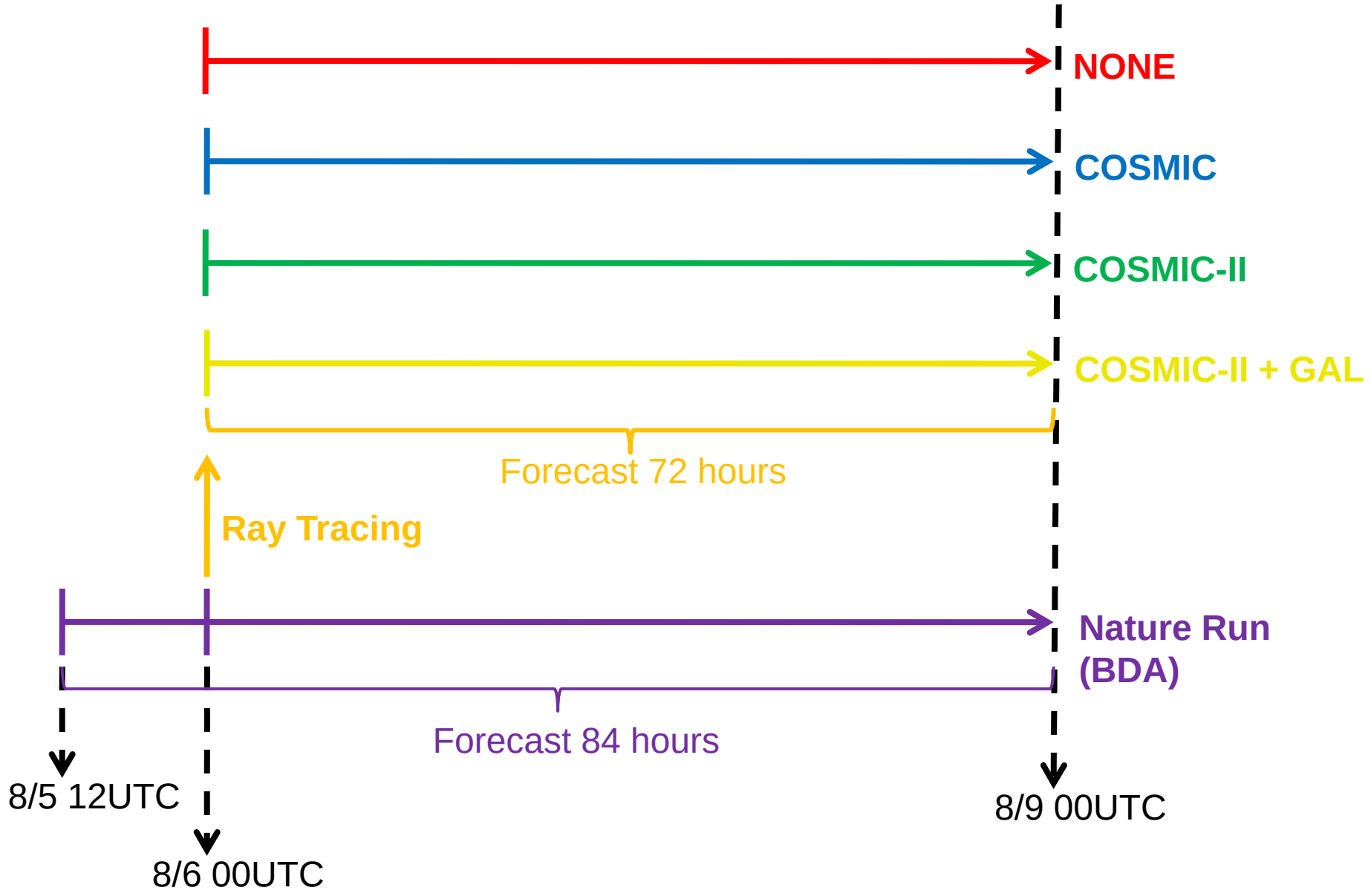
Regional hourly RO samples



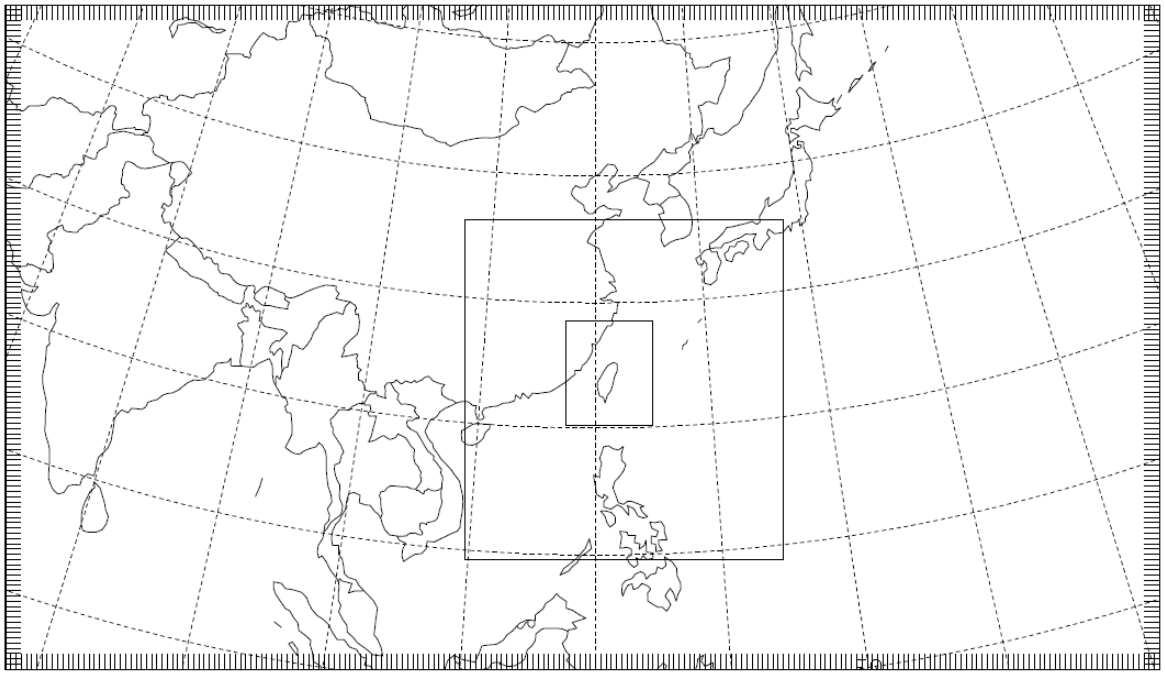
OSSE flow chart for Morakot



Morakot (2-h assimilation window)



Morakot OSSE (WRF ; 3DVAR)



WRF V3.1.1

Input Data :
NCEP/NCAR Reanalysis

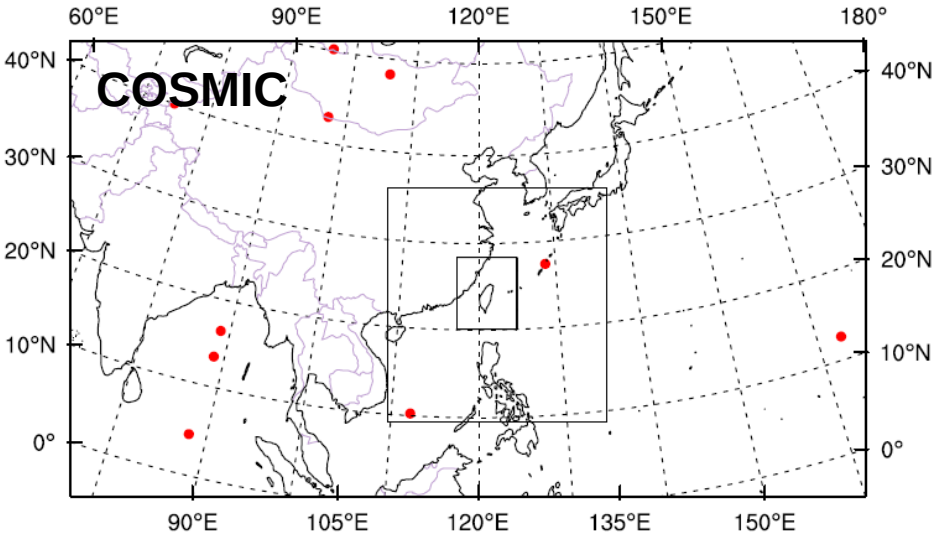
Domain :
D01 : 222 ×128 ×45 (45km)
D02 : 184 ×196 ×45 (15km)
D03 : 151 ×181 ×45 (5km)

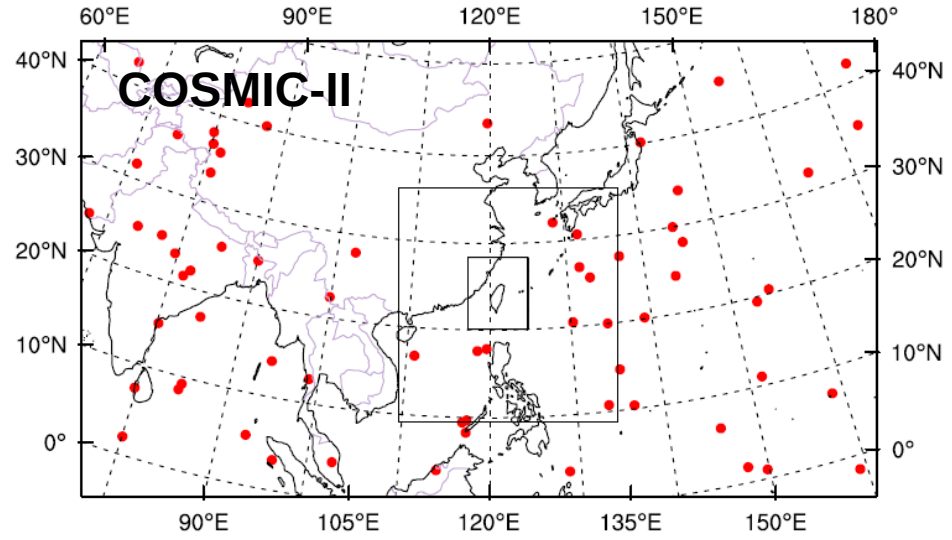
Model Top :
30hPa

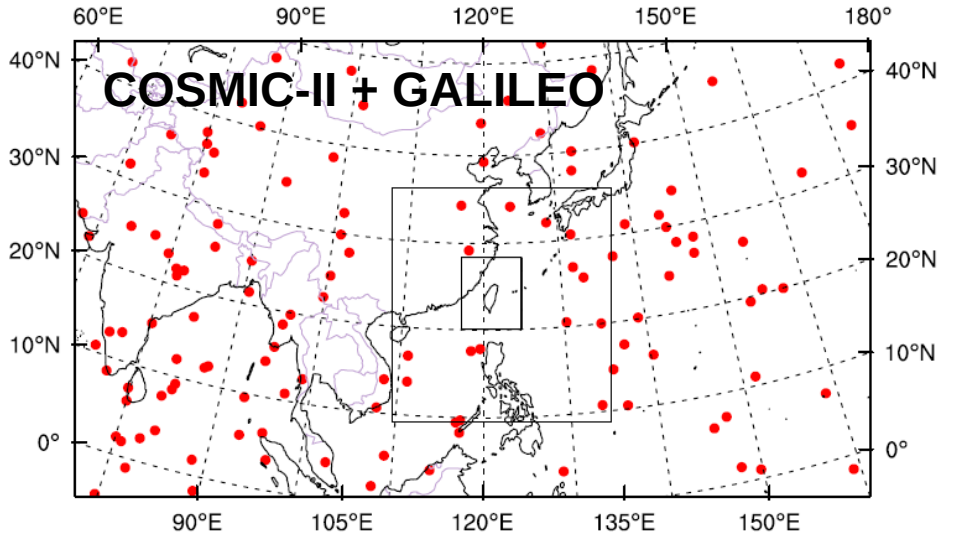
Starting Time :
2009/08/06 00UTC

Ending Time :
2009/08/09 00UTC

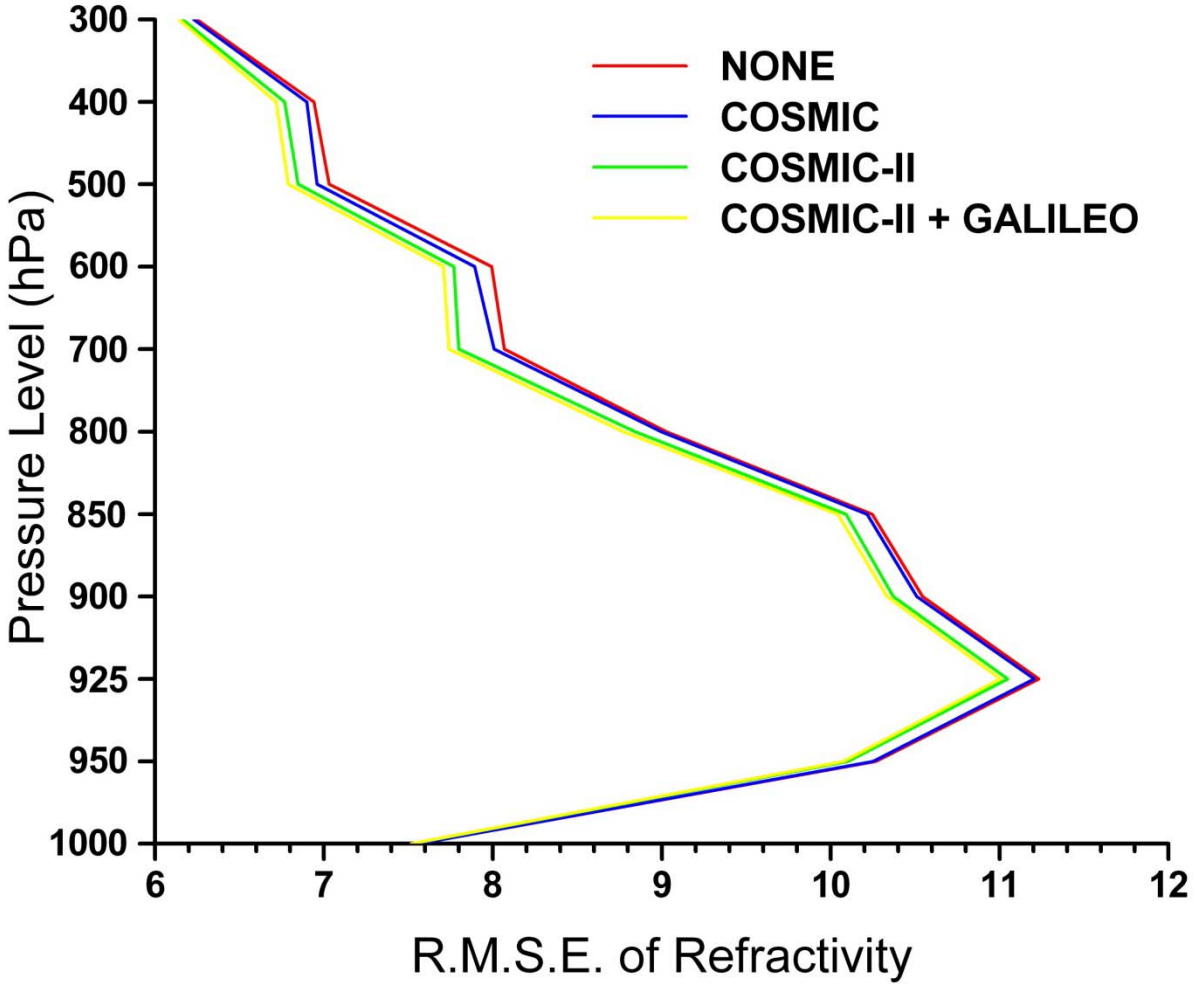
Physics Options in WRF :	
Explicit Moisture Schemes	Goddard microphysics scheme (7,7,7)
Cumulus Parameterizations	Grell-Devenyi ensemble scheme (D01 & D02) (3,3,0)
PBL Schemes	Yonsei University scheme (1,1,1)
Radiation Schemes	RRTM scheme (Rapid Radiative Transfer Model) (1,1,1)
Surface Schemes	Noah Land Surface Model (2,2,2)



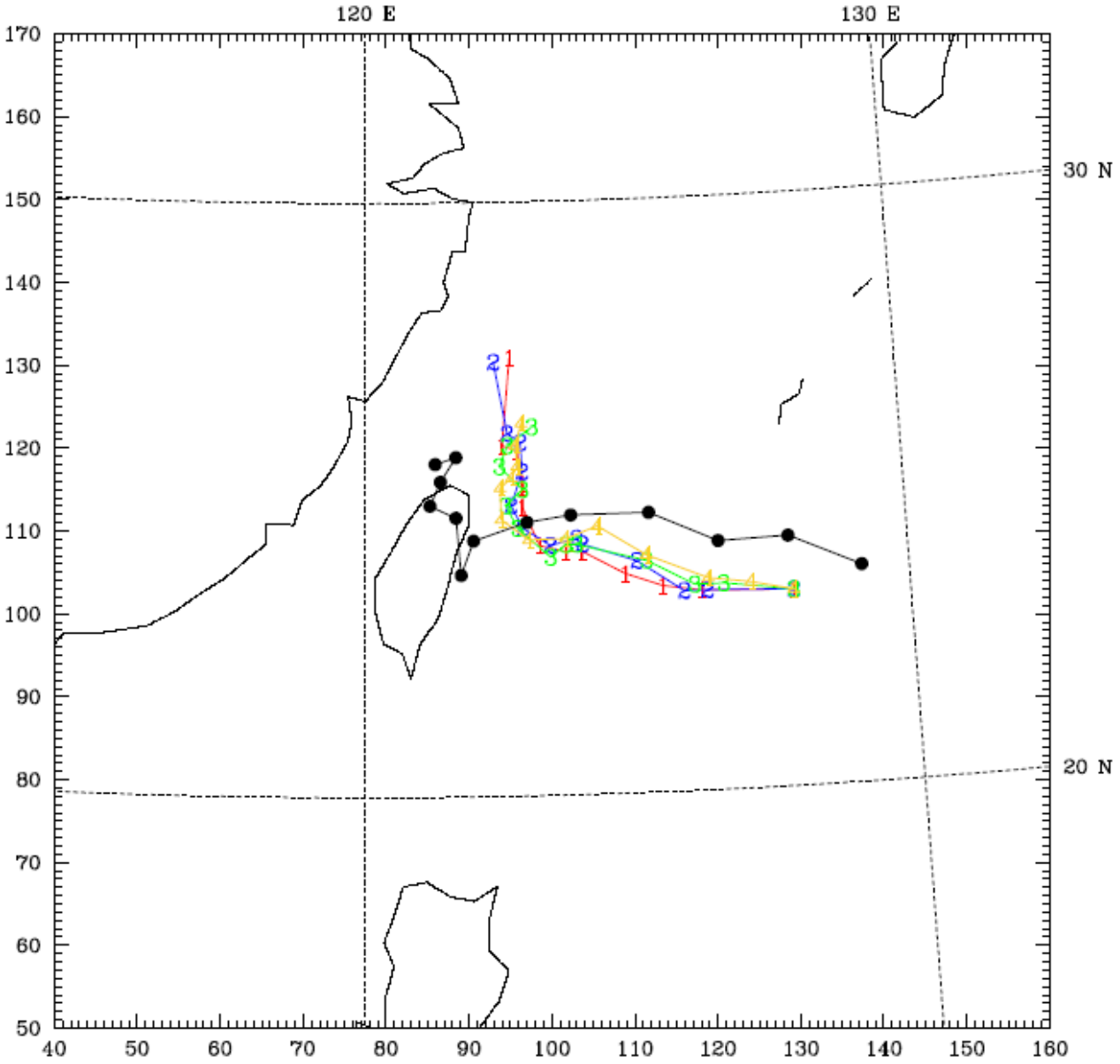


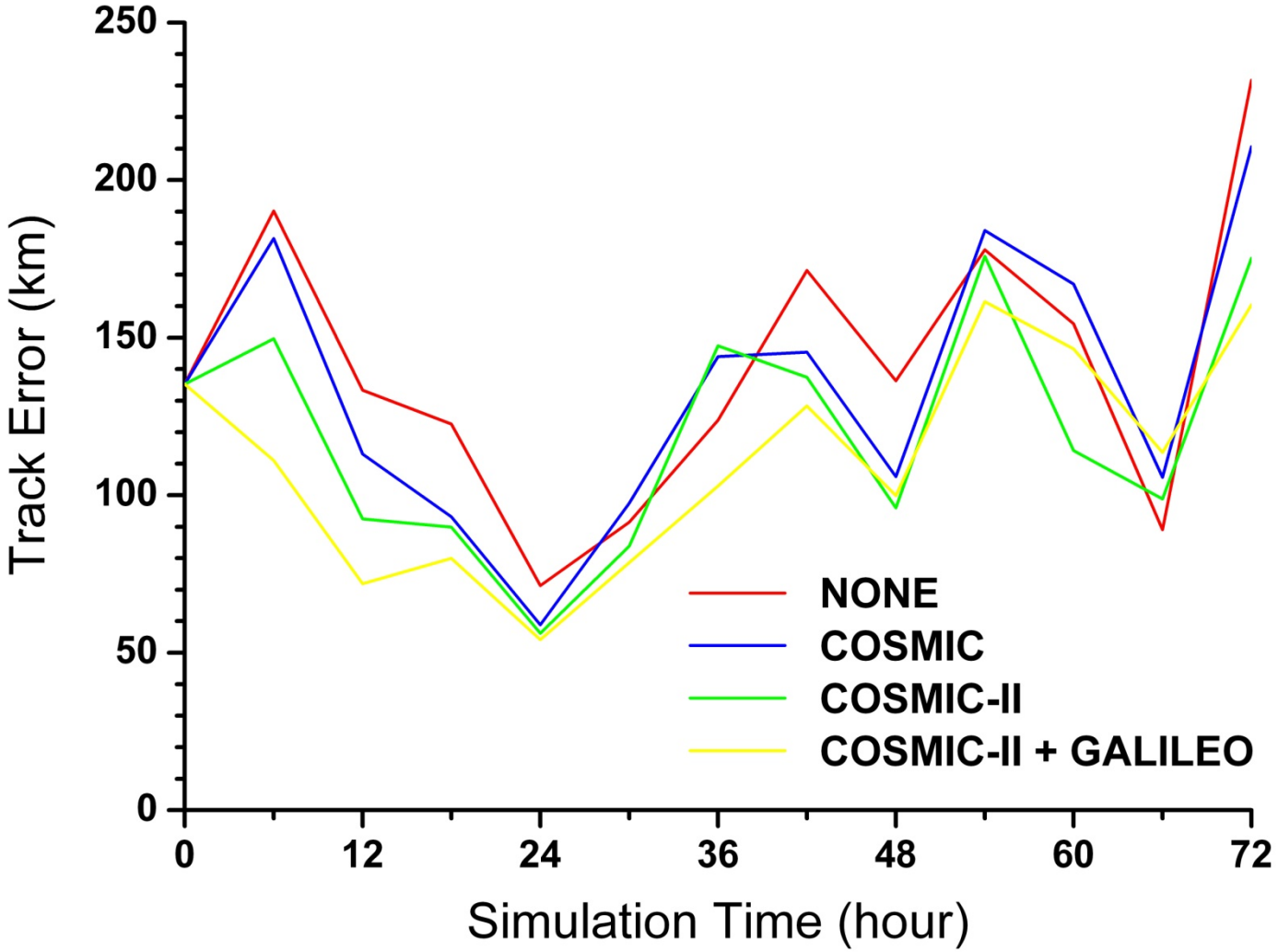


	Domain 1	Domain 2	Domain 3
COSMIC	10	2	0
COSMIC-II	67	11	0
COSMIC-II + GALILEO	125	15	0

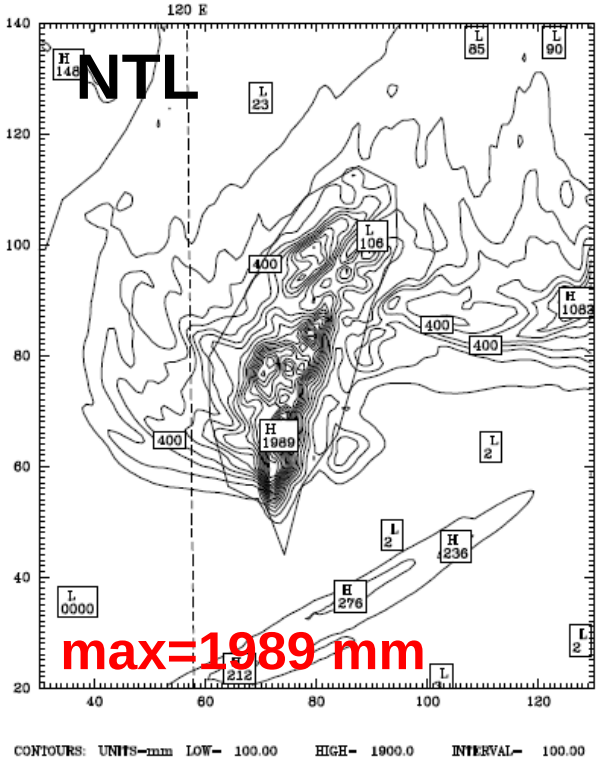


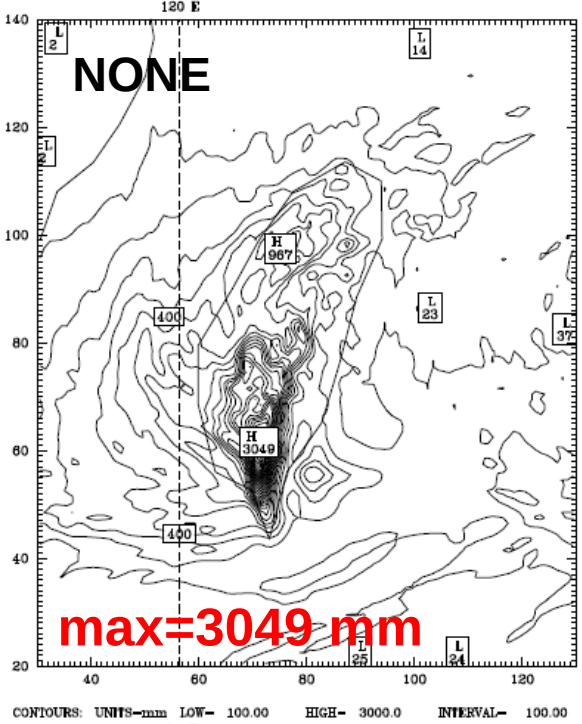
CASE	U (m/s)	V (m/s)	T (k)	Q (g/kg)	P (hPa)	REF
NONE	3.36	2.92	1.73	1.24	13.45	8.75
COSMIC	3.33	2.92	1.76	1.23	13.45	8.71
COSMIC-II	3.31	2.91	1.88	1.22	13.45	8.57
COSMIC-II + GALILEO	3.29	2.93	1.94	1.22	13.45	8.53

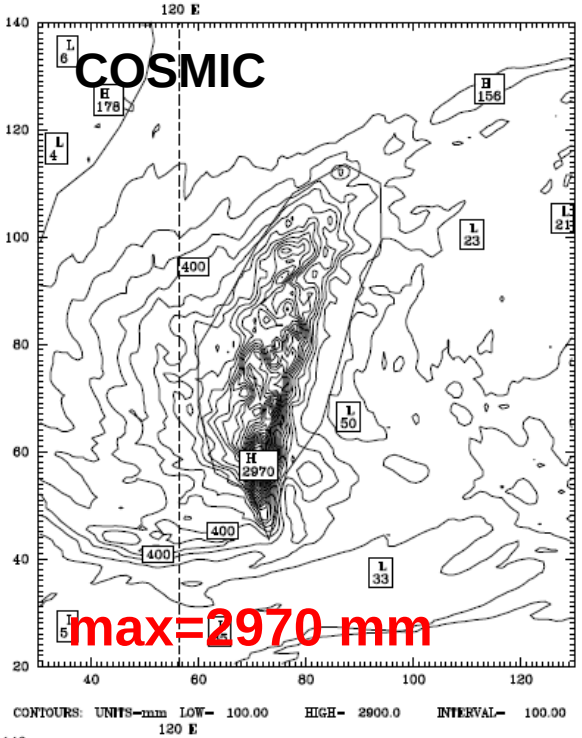

120 E
130 E
30 N
20 N
170
160
150
140
130
120
110
100
90
80
70
60
50
40
50
60
70
80
90
100
110
120
130
140
150
160

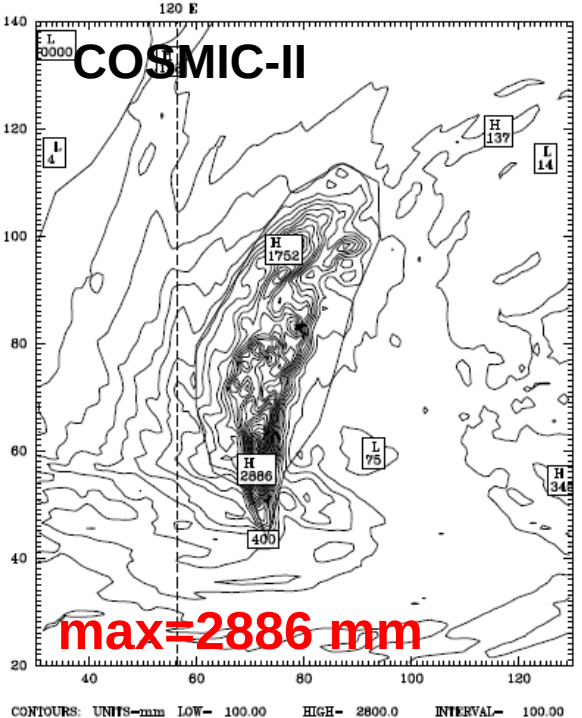


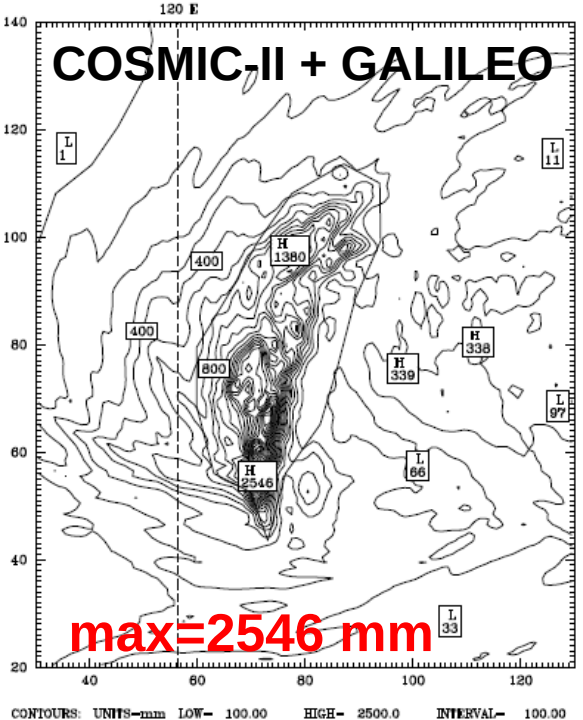
Experiment	NONE	COSMIC	COSMIC-II	COSMIC-II + GALILEO
Mean Track Error (km)	141	134	119	111

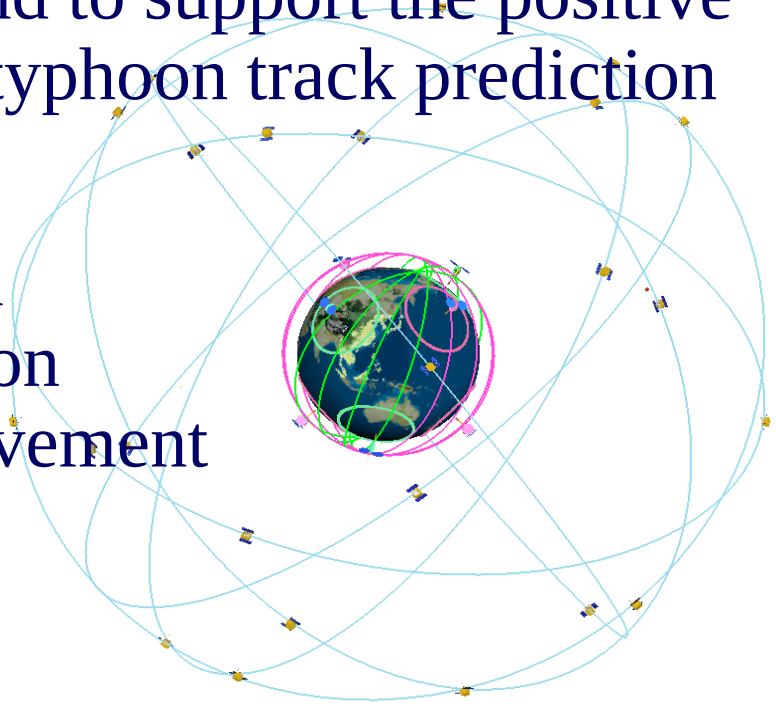

NTL
120 E
max=1989 mm
CONTOURS: UNITS=mm LOW= 100.00 HIGH= 1900.0 INTERVAL= 100.00


NONE
120 E
max=3049 mm
CONTOURS: UNITS=mm LOW= 100.00 HIGH= 3000.0 INTERVAL= 100.00


COSMIC
120 E
max=2970 mm
CONTOURS: UNITS=mm LOW= 100.00 HIGH= 2900.0 INTERVAL= 100.00


COSMIC-II
120 E
max=2886 mm
CONTOURS: UNITS=mm LOW= 100.00 HIGH= 2800.0 INTERVAL= 100.00


COSMIC-II + GALILEO
120 E
max=2546 mm
CONTOURS: UNITS=mm LOW= 100.00 HIGH= 2500.0 INTERVAL= 100.00

CONCLUSIONS

- The real case simulation results indicate that the GPS RO data have some positive impacts on typhoon track prediction, which in turns improve the ensuing rainfall prediction over local regions.
- The OSSE studies for F7/C2 tend to support the positive impacts of the GPS RO data on typhoon track prediction under current deployment plan.
- Advanced data assimilation with more reliable RO data information will be helpful for further improvement of typhoon prediction.