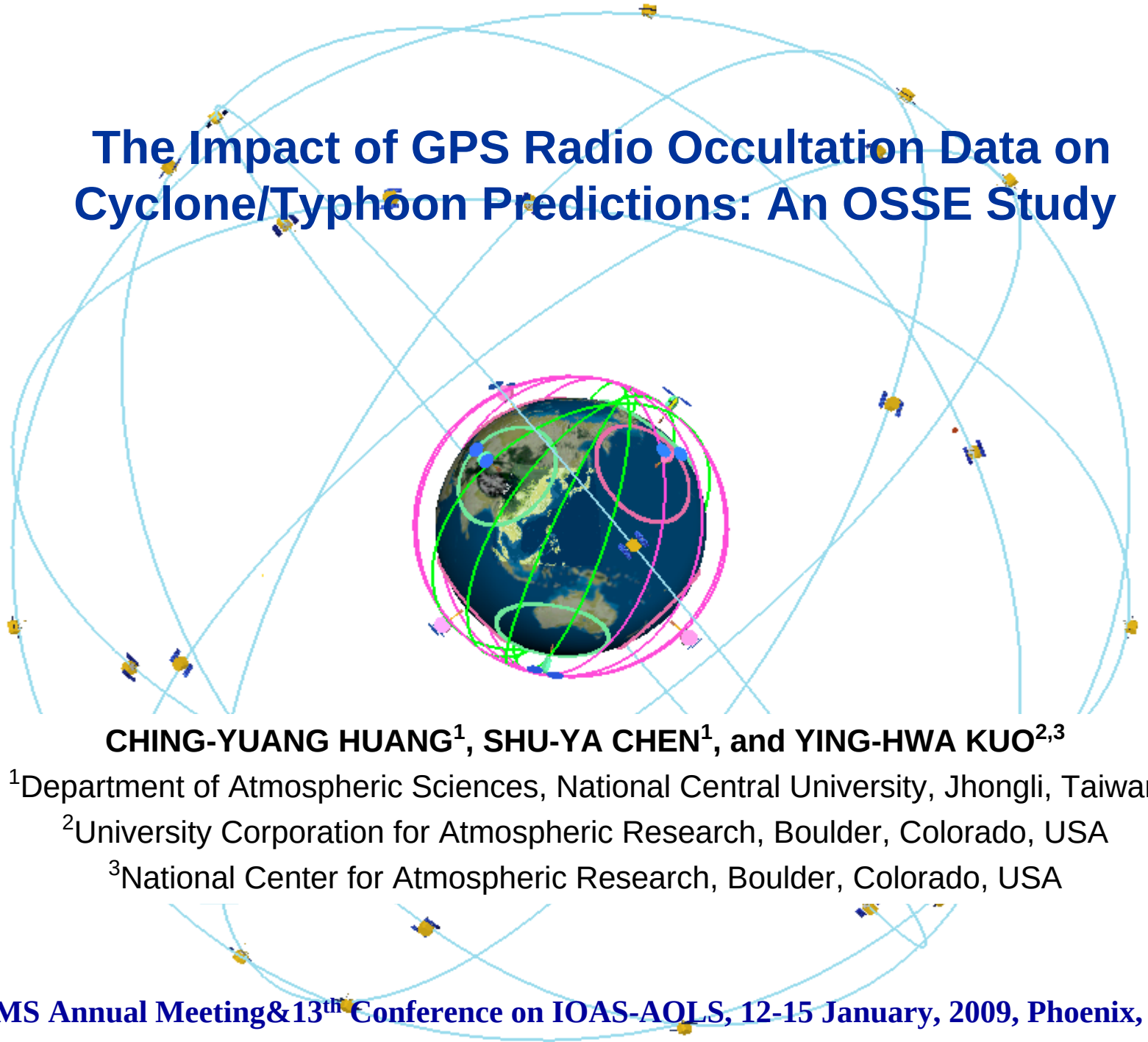
The Impact of GPS Radio Occultation Data on Cyclone/Typhoon Predictions: An OSSE Study



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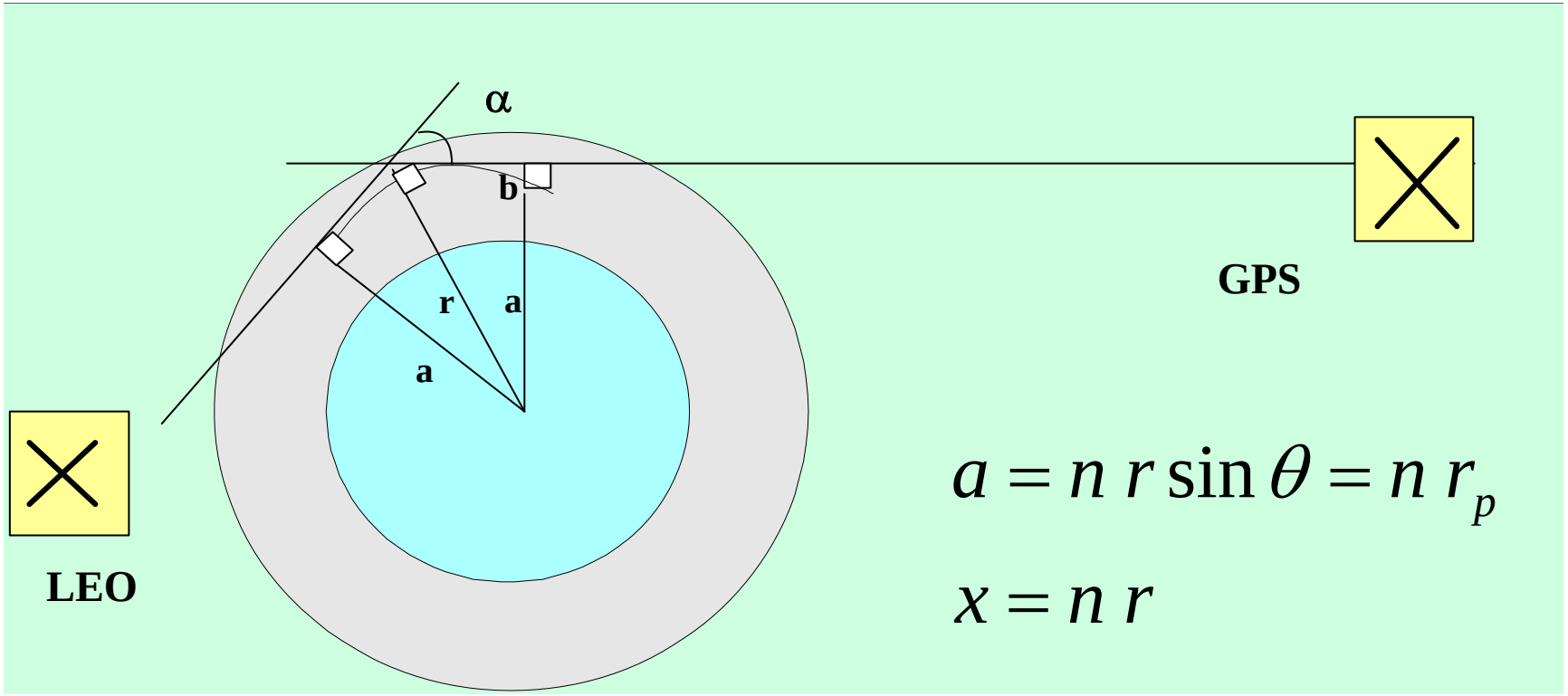
89th AMS Annual Meeting&13th Conference on IOAS-AOLS, 12-15 January, 2009, Phoenix, Arizona

Outline

- Introduction: observation operators, past efforts
- Recent weather (typhoon) predictions with assimilation of FORMOSAT-3/COSMIC RO data in 2007 and 2008
- The impact of idealized GPS RO data on Prediction of Typhoons Krosa (2007):
  An Observing-Systems Simulation Experiments (OSSE) Study
- Conclusions

The GPS Radio Occultation



$$a = n\, r \sin\theta = n\, r_p$$

$$x = n\, r$$

Forward Propagation

$$\alpha(a) = -2a \int_x^{\infty} \frac{d\ \ln(n) / dx}{\sqrt{x^2 - a^2}}\, dx$$

Abel Inversion

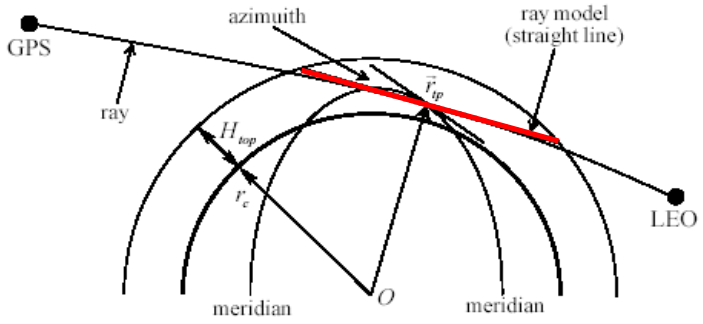
$$\ln(n(x)) = \frac{1}{\pi} \int_x^{\infty} \frac{\alpha(a)}{\sqrt{a^2 - x^2}}\, da$$

The nonlocal operator

- Abel-retrieved refractivity accounts for an integrated amount of refractivity along the total path of the ray in a spherically-symmetric atmosphere.
- To take the effect of horizontal gradients into account, Sokolovskiy et al. (2005) suggest assimilation of excess phase, defined as the integrated refractivity along a straight ray.

Nonlocal (excess phase):

$$S = \int N \cdot dl$$



- A nonlocal operator was implemented into the WRFVAR 2.1 (Chen et al. 2008).

→ Local operator assimilating N at the perigee point.

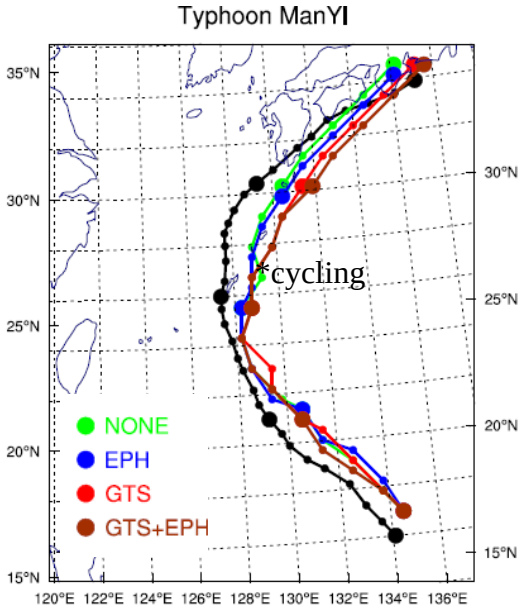
$$N = (n-1)\times 10^6 = 77.6\frac{P}{T} + 3.73\times 10^5 \frac{P_w}{T^2} - 40.3\times 10^{-12}\frac{n_e}{f^2}$$

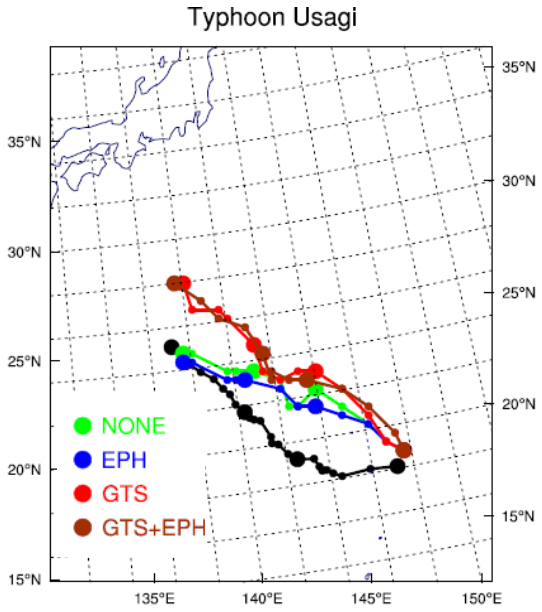
The simulated severe weather cases in 2006, 2007 with FORMOSAT-3 RO data.

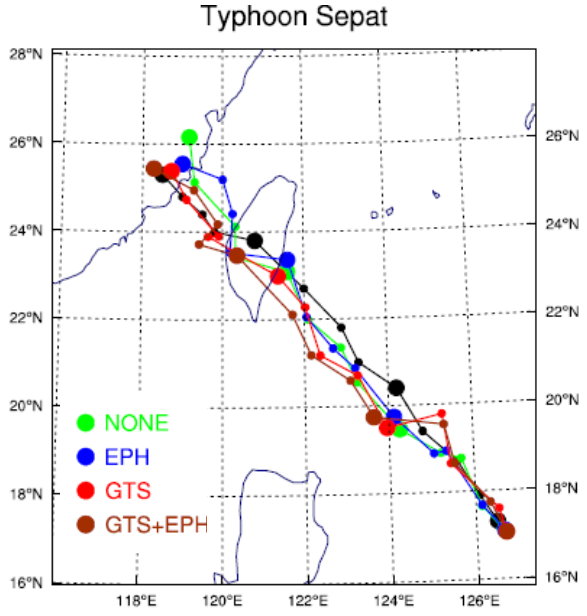
Initial Time	Event	GPS RO
2006-07-1200	Typhoon Bilis	**2**
2006-07-2300	Typhoon Kaemi	**7**
2006-09-1312	Typhoon Shanshan	**27**
2007-06-0212	Meiyu Front	**31**
2007-06-0300	Cyclone Gonu	**56**
2007-07-1100	Typhoon Manyi	**15**
2007-07-2900	Typhoon Usagi	**39**
2007-08-1600	Typhoon Sepat	**21**
2007-10-0412 (0500)*	Typhoon Krosa	**31 (17) * cycling**

EPH: excess phase (nonlocal operator)

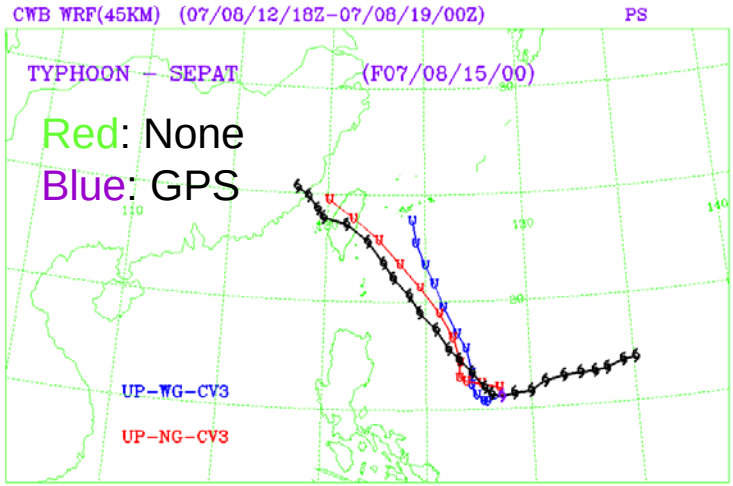
WRF- 3 domains

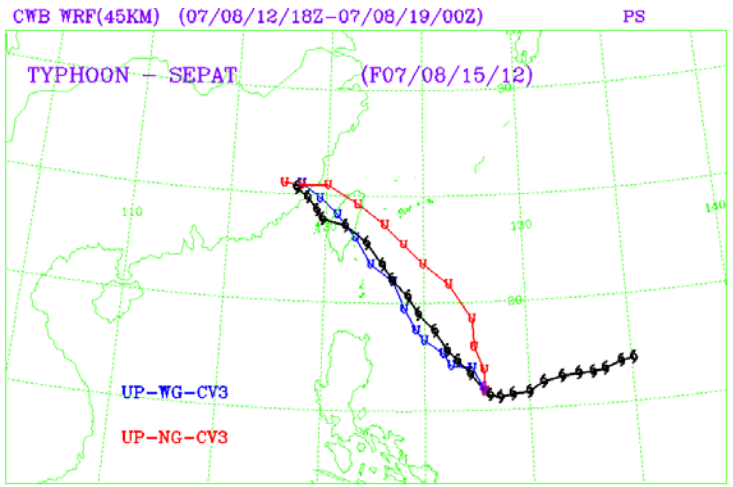






SEPAT **2008/08/1500Z** **2008/08/1512Z**





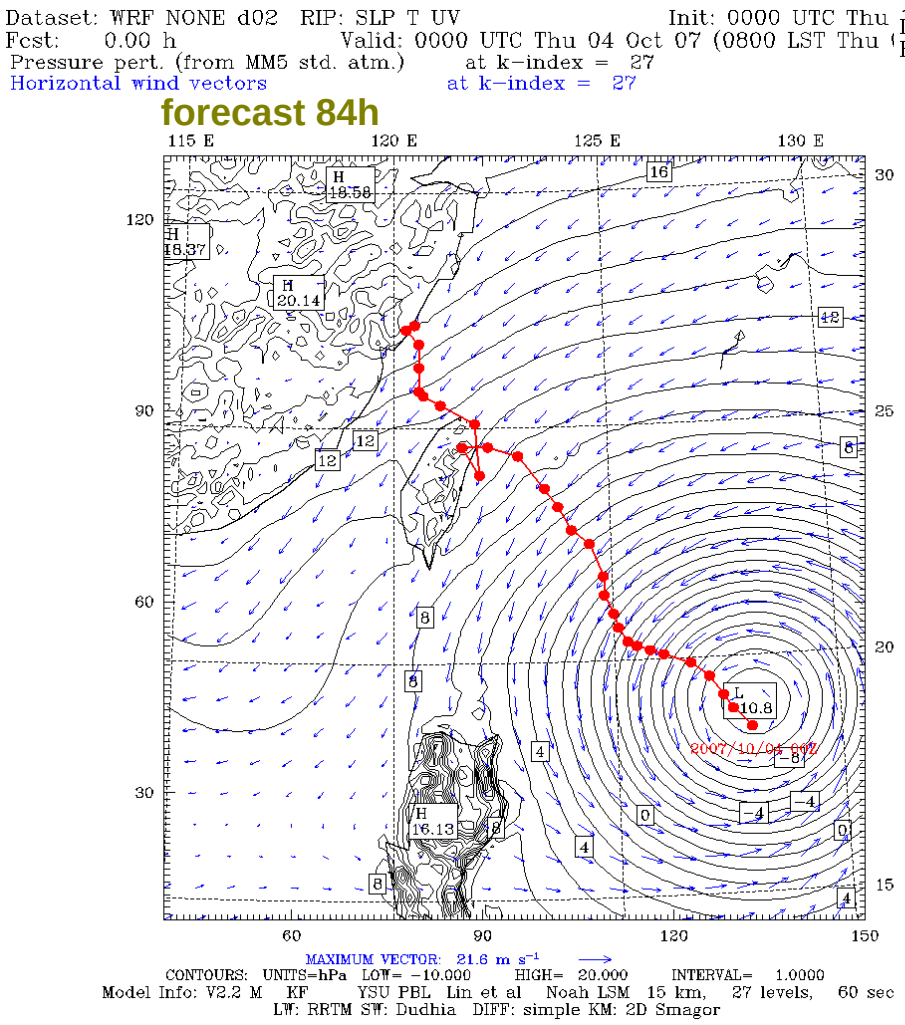
CWB WRF operational runs

track errors (red is better)

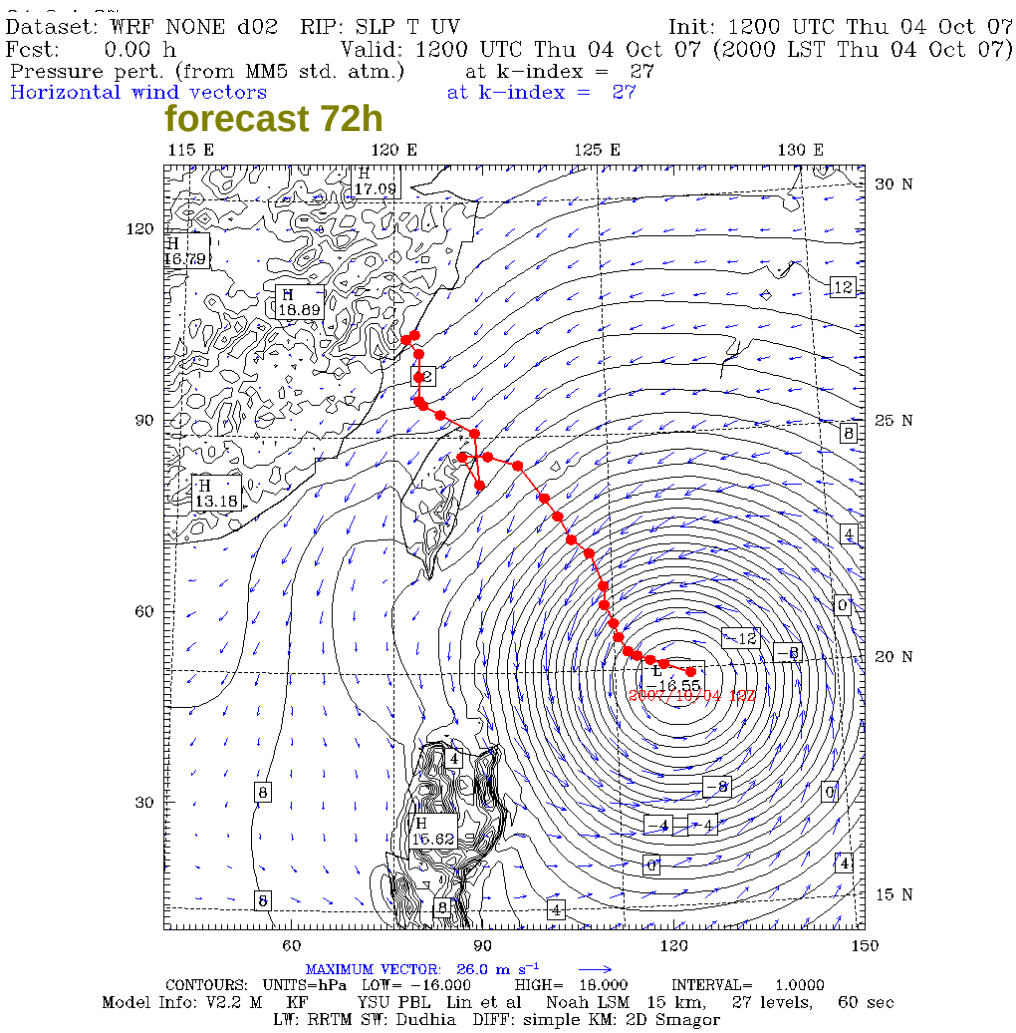
	12HR	24HR	36HR	48HR	60HR	72HR
1312	0.88	1.11	1.67	1.69	1.92	2.08
1400	5.42	1.43	2.98	4.84	7.65	4.98
1412	0.58	0.20	0.21	0.04	0.04	0.27
1500	2.59	1.55	1.90	2.64	1.80	2.16
1512	0.29	0.36	0.36	0.29	0.31	0.71
1600	0.48	0.14	0.18	0.31	0.5	0.66
1612	0.30	0.70	0.79	0.90	1.01	
1700	0.90	1.65	1.09	0.81		
1712	1.57	1.22	1.46			
1800	0.46	0.16				

WRF (with AVN) for Typhoon Krosa

2007/10/04 0000UTC



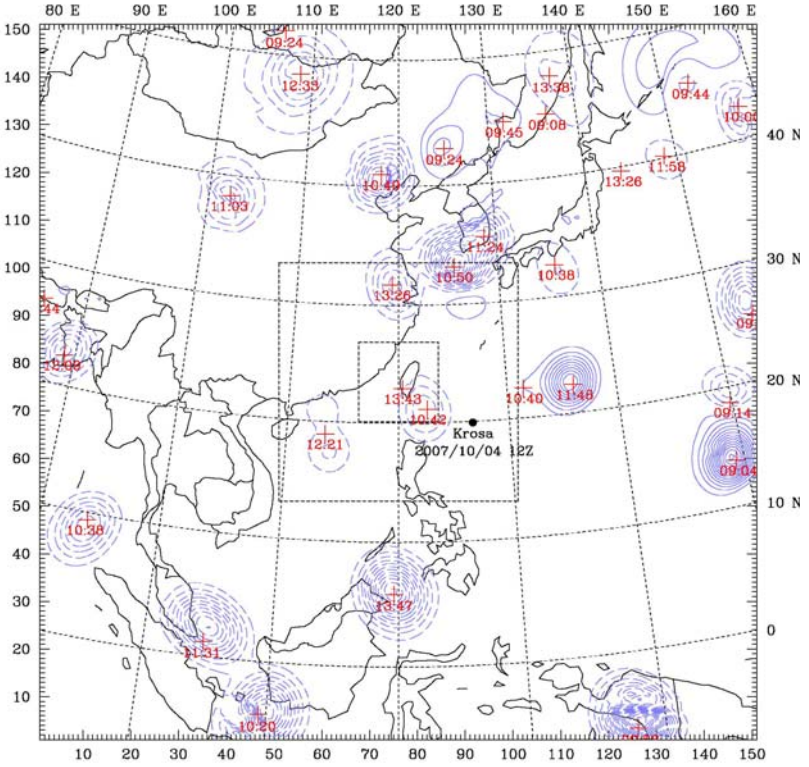
2007/10/04 1200UTC



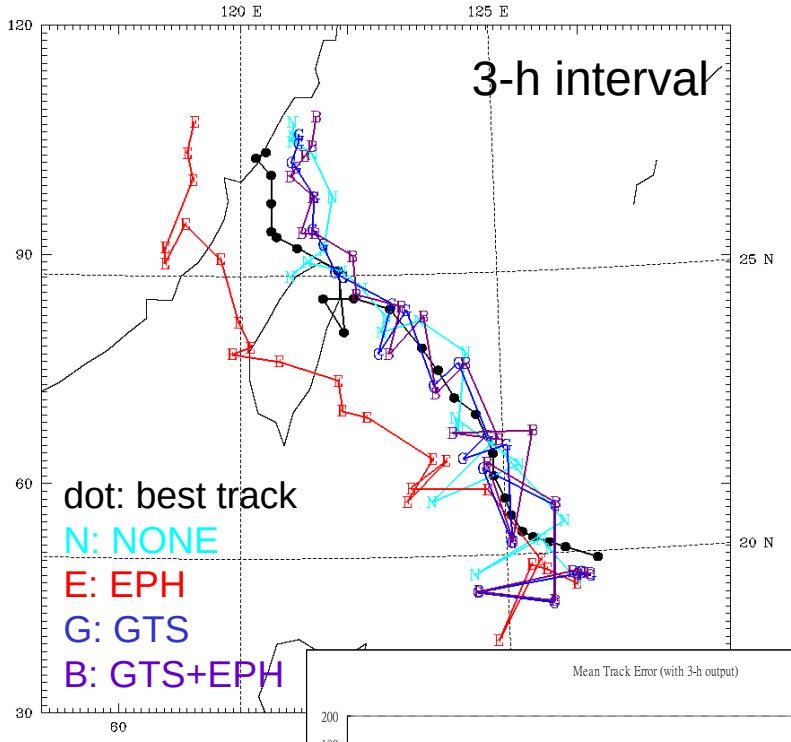
Compared with best tracks (red dotted-line) from http://agora.ex.nii.ac.jp/digital-typhoon/

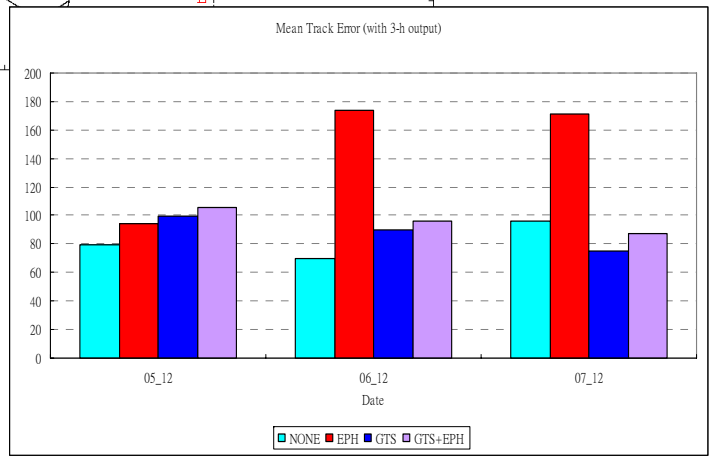
Typhoon Krosa (2007/10/04 12UTC)

Increments of N



Simulated tracks

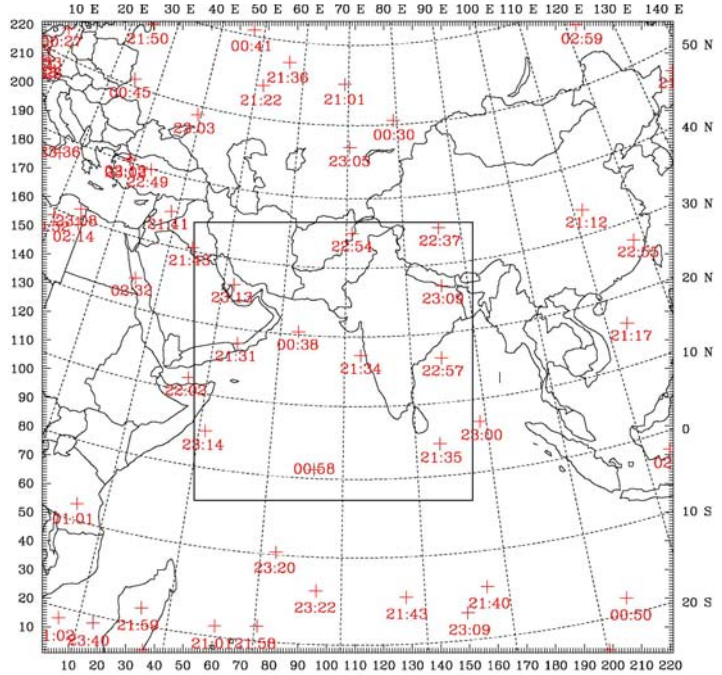


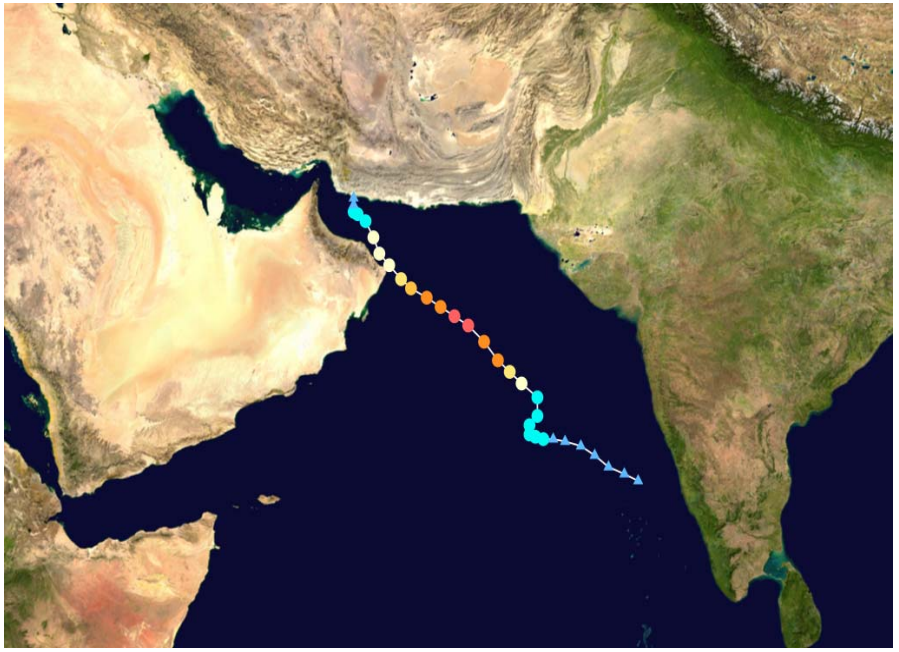


Assimilation for 3 domains

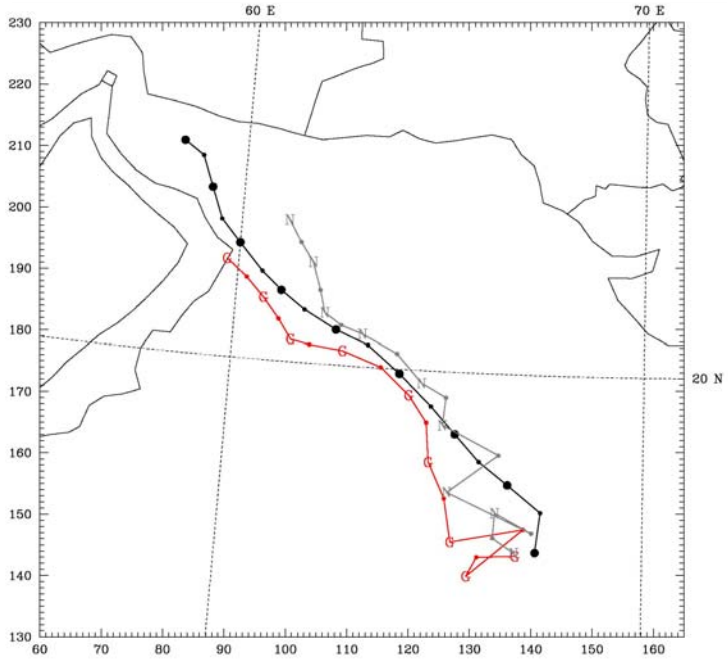
31 GPS RO Soundings

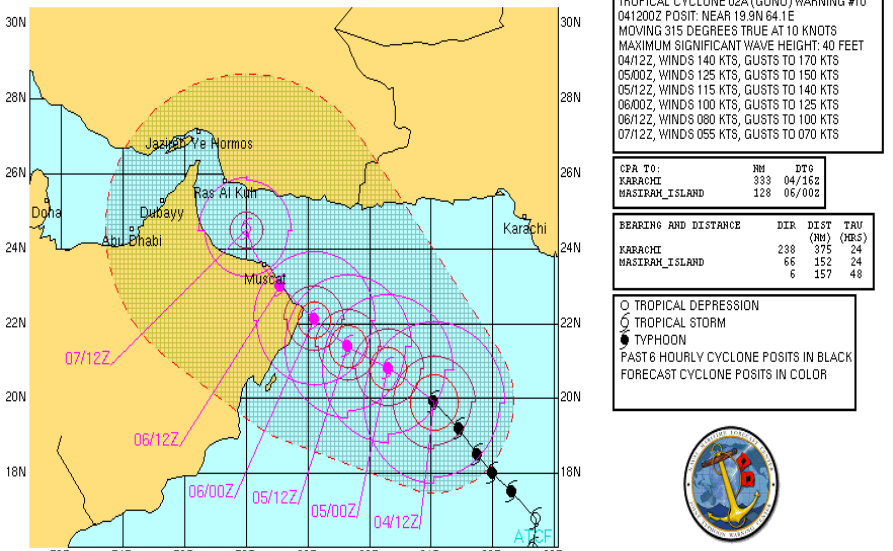
a





b



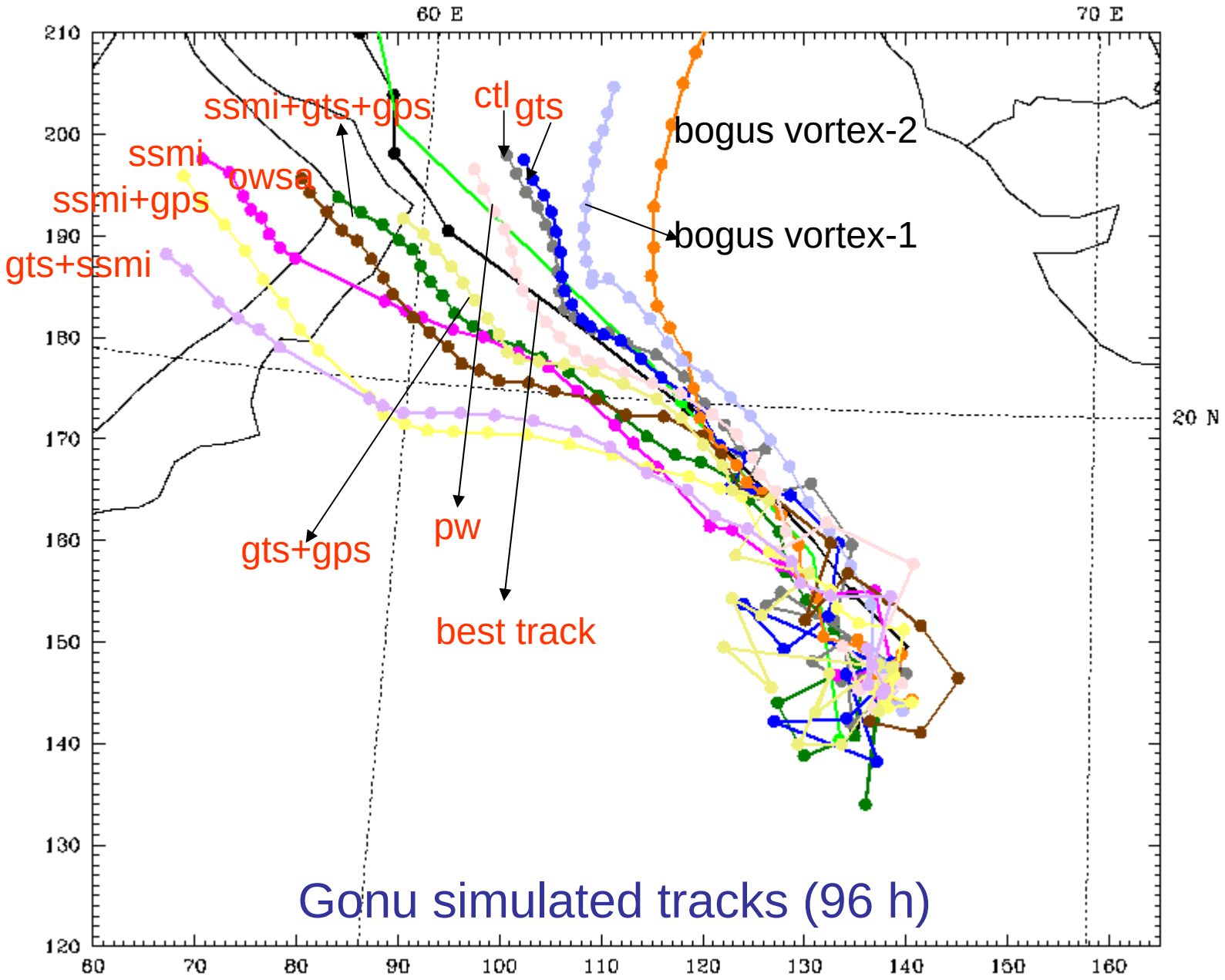


Gonu Cyclone: 03 June 2007. (56 GPS RO)

Gonu Assimilation Experiments

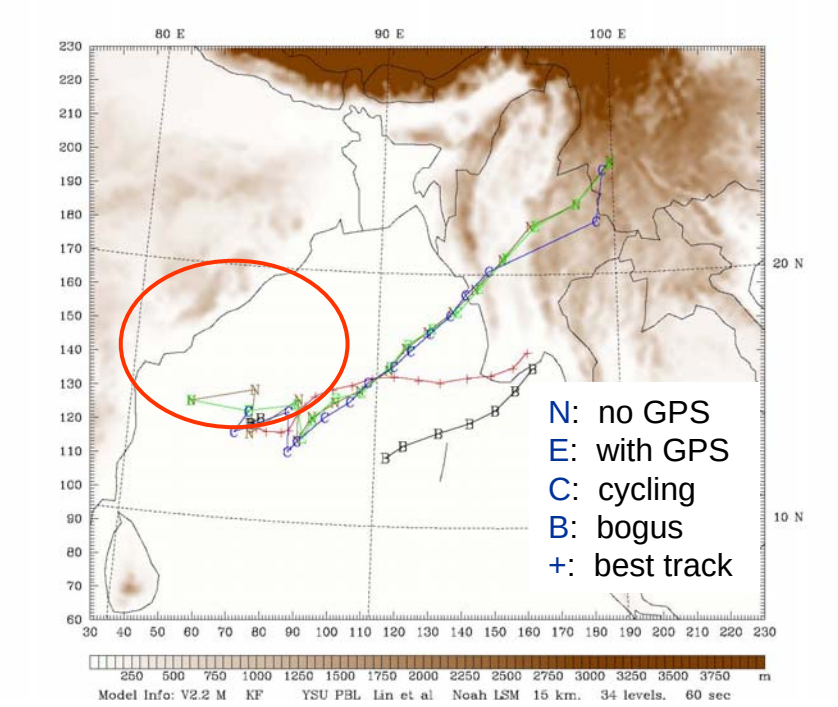
- Control Run (CTL)
- GTS
- SSM/I
- COSMIC (GPS)
- Bogus Vortex test -1 (small)
- Bogus Vortex test -2 (large)
- SGC (SSM/I+GTS+COSMIC)
- OWSA (SSM/I)
- IWVA (SSM/I)
- SSM/I+GPS
- GTS+GPS
- GTS+SSMI

Twelve combinations


60 E
70 E
20 N
ssmi+gts+gps
ctl
gts
bogus vortex-2
ssmi
owsa
ssmi+gps
bogus vortex-1
gts+ssmi
pw
gts+gps
best track
Gonu simulated tracks (96 h)

The impact of FORMOSAT-3/COSMIC RO data on recent severe weather predictions in 2008

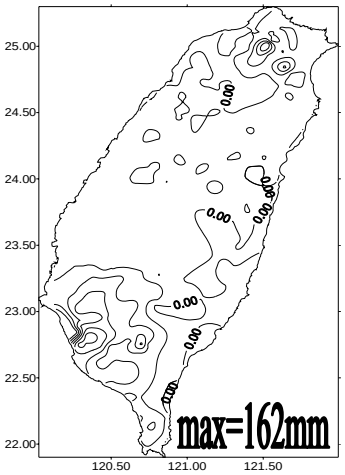
Initial Time	Event	GPS RO
2008-04-2900 (2906)*	Cyclone Nargis	21 (24)
2008-06-2500	Meiyu Front	26
2008-07-1600	Typhoon Kalmaegi	15
2008-07-2600	Typhoon Fung-Wong	43
2008-09-1200	Typhoon Sinlaku	12
2008-09-2700	Typhoon Jangmi	27



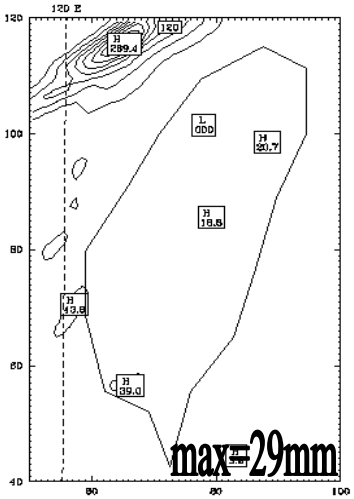
Case	Assimilated data
None	no
GPS	FORMOSAT-3 GPS RO refractivity (EPH)
GTS	NCAR GTS data
Drop	Soundings
SSM/I	PW and 2D wind speed

Int:30 mm **Meiyu front-** 2007/0625 0000UTC

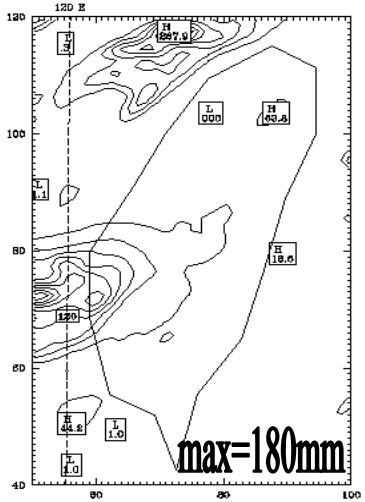
OBS



None

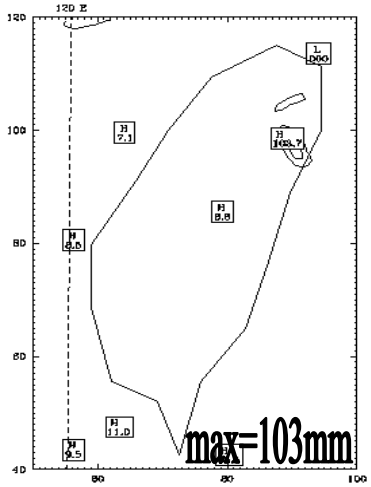


GPS

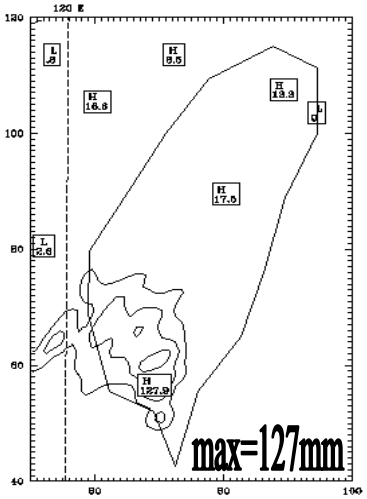


WRF simulated 24-h accumulated rainfall (mm) (0628 0000 – 0629 0000 UTC)

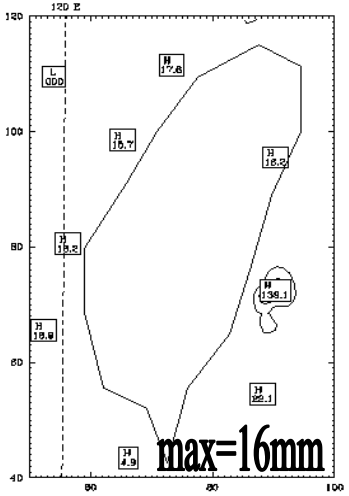
GTS



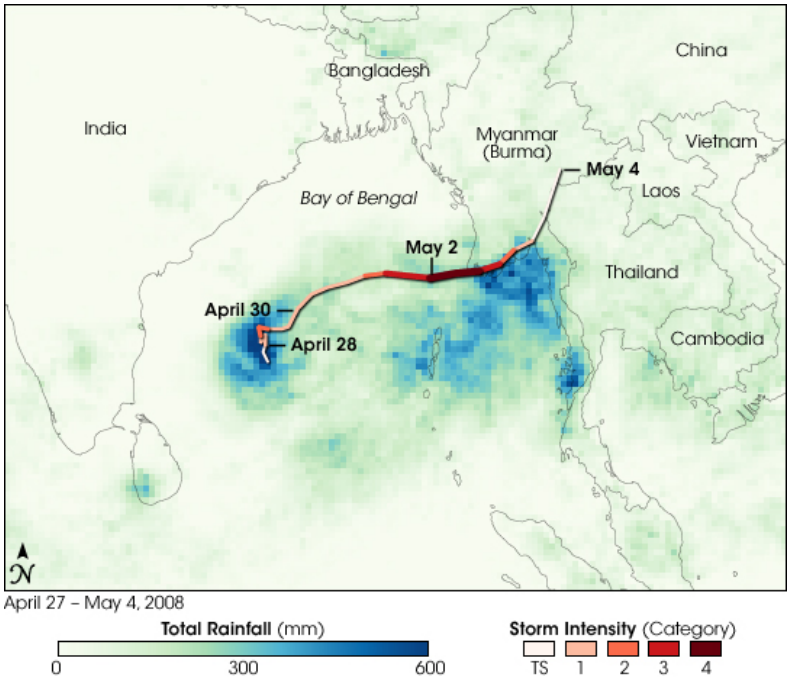
Drop

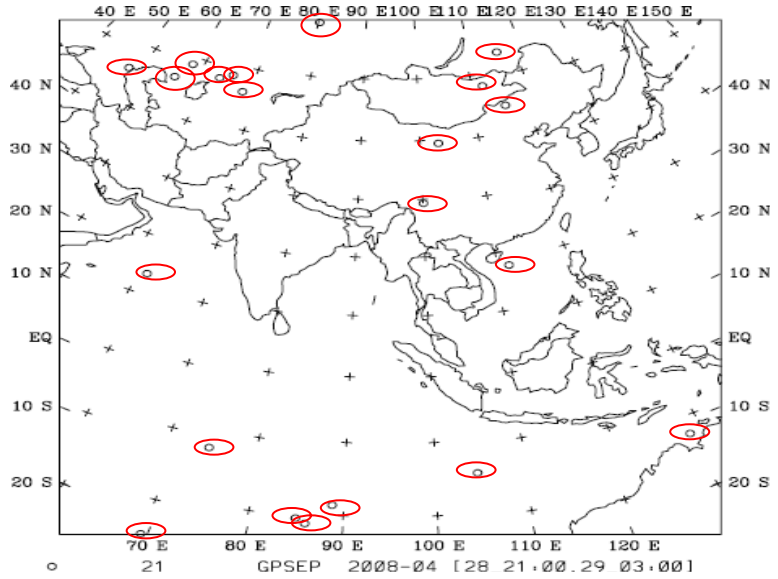


SSM/I



Myanmar Cyclone Nargis (2008)





21 GPS RO points

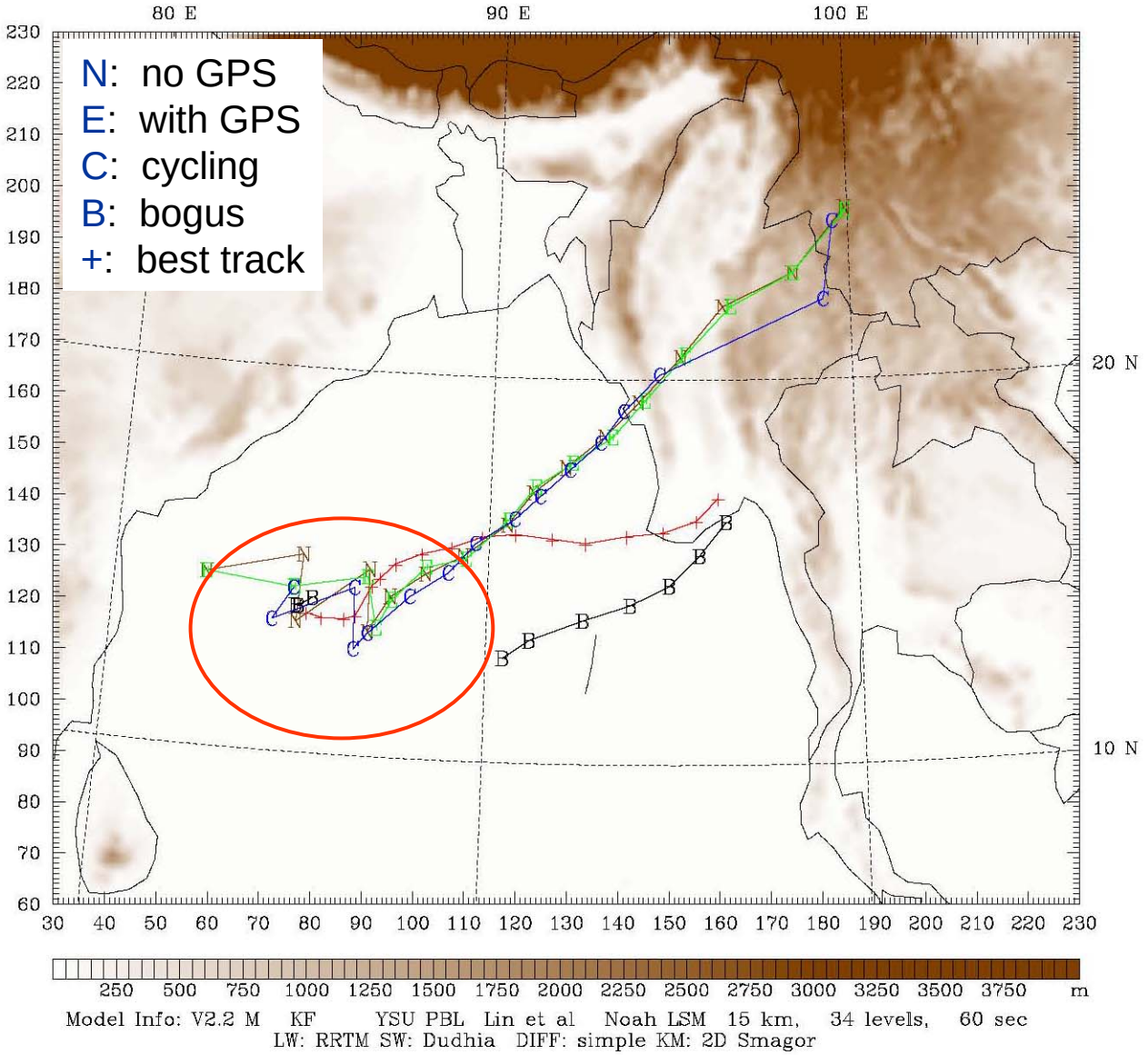
Rainfall accumulations along Cyclone Nargis
by Tropical Rainfall Measuring Mission (TRMM) satellite
(http://earthobservatory.nasa.gov)

Use WRF 2-domains
(45-km and 15-km)

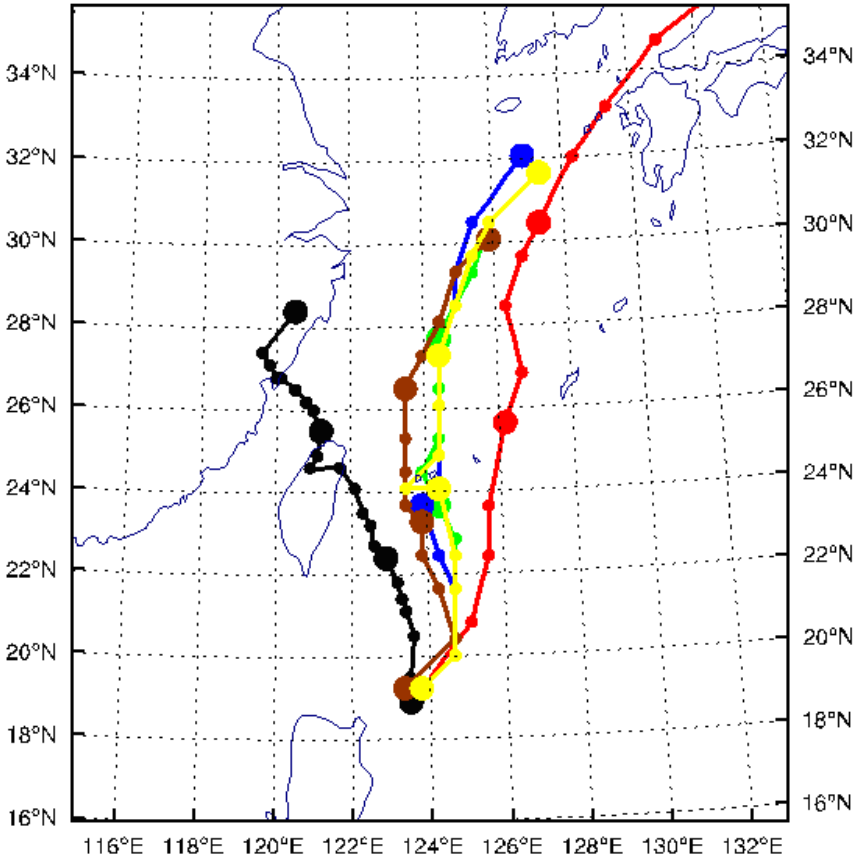
A perfect cyclone!

From 0000UTC 29 April 2008

Dataset: eph RIP: Track nargis track Init: 0000 UTC Tue 29 Apr 08
Fcst: 0.00 h Valid: 0000 UTC Tue 29 Apr 08 (0800 LST Tue 29 Apr 08)
Terrain height AMSL

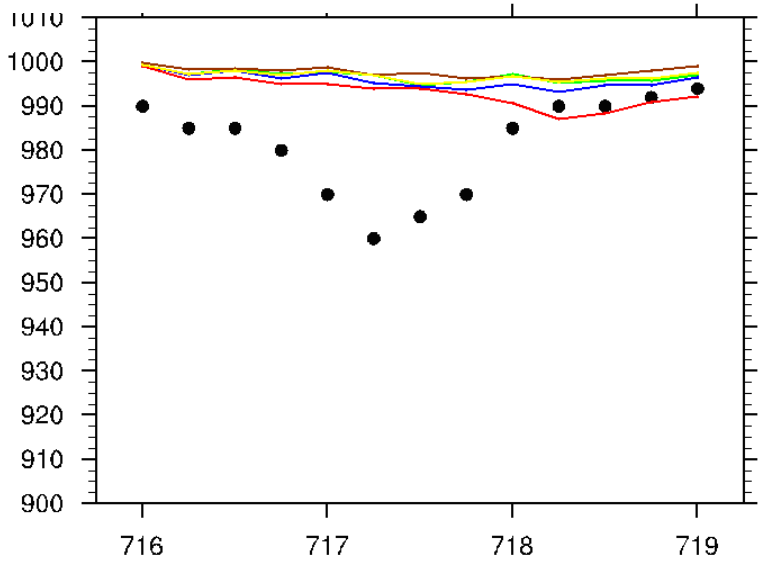


Typhoon Kalmaegi (2008/0716)



~ 0000 UTC 16 July 2008 for 72 h

- BTrack.jp
- None
- Dropsonde (6 points)
- GPS (15 points)
- GTS (with QuikSCAT data)
- SSM/I



A challenging case!

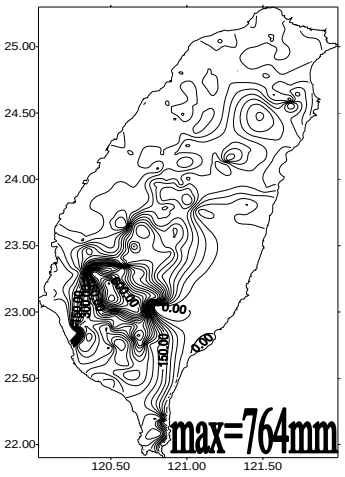
Drop: Choose **7/16 0000 UTC** (***0h)*** **~ *+12h*** for data assimilation

Int:30 mm

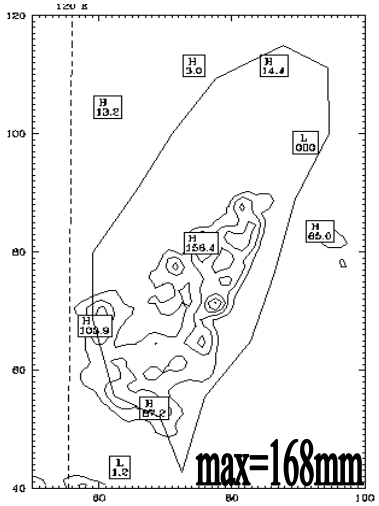
2nd day

Kalmaegi

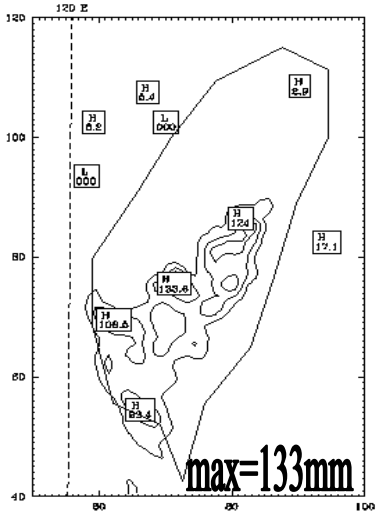
OBS



None

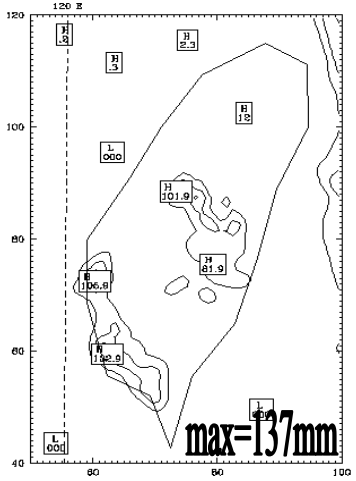


GPS

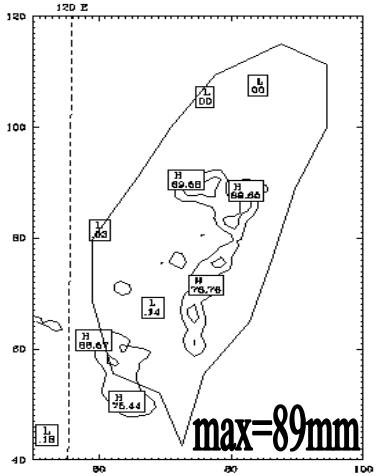


WRF simulated 24-h accumulated rainfall (mm) (0717 0000 – 0718 0000 UTC)

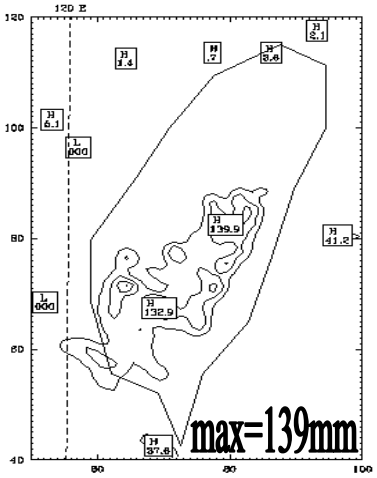
GTS



Drop



SSM/I

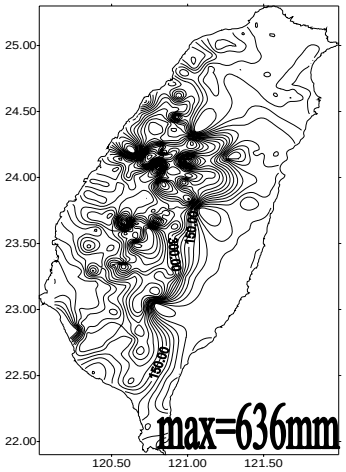


Int:30 mm

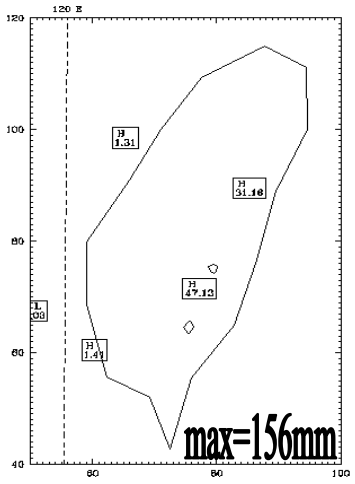
3rd day

Kalmaegi

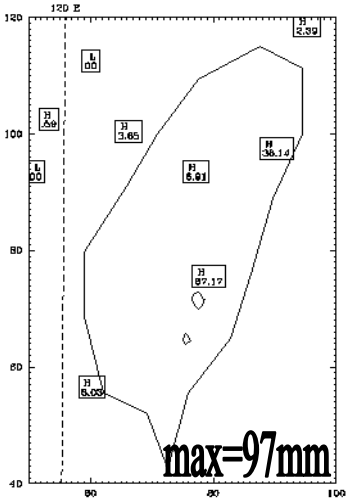
OBS



None

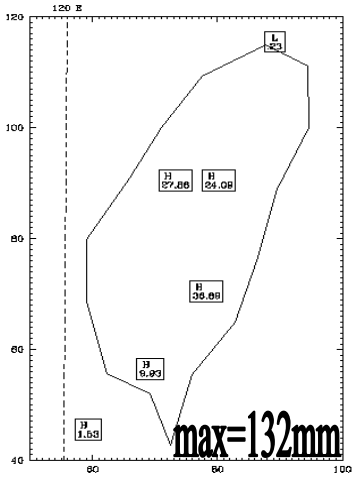


GPS

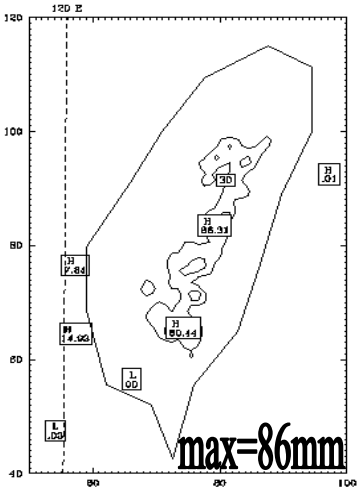


WRF simulated 24-h accumulated rainfall (mm) (0718 0000 – 0719 0000 UTC)

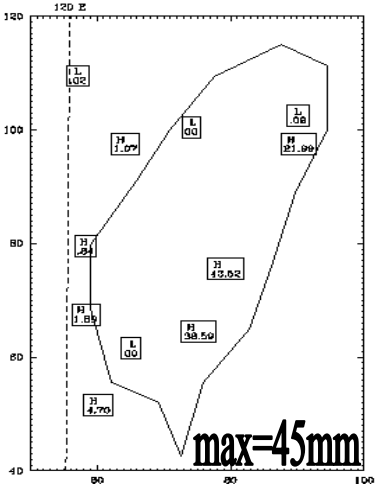
GTS



Drop

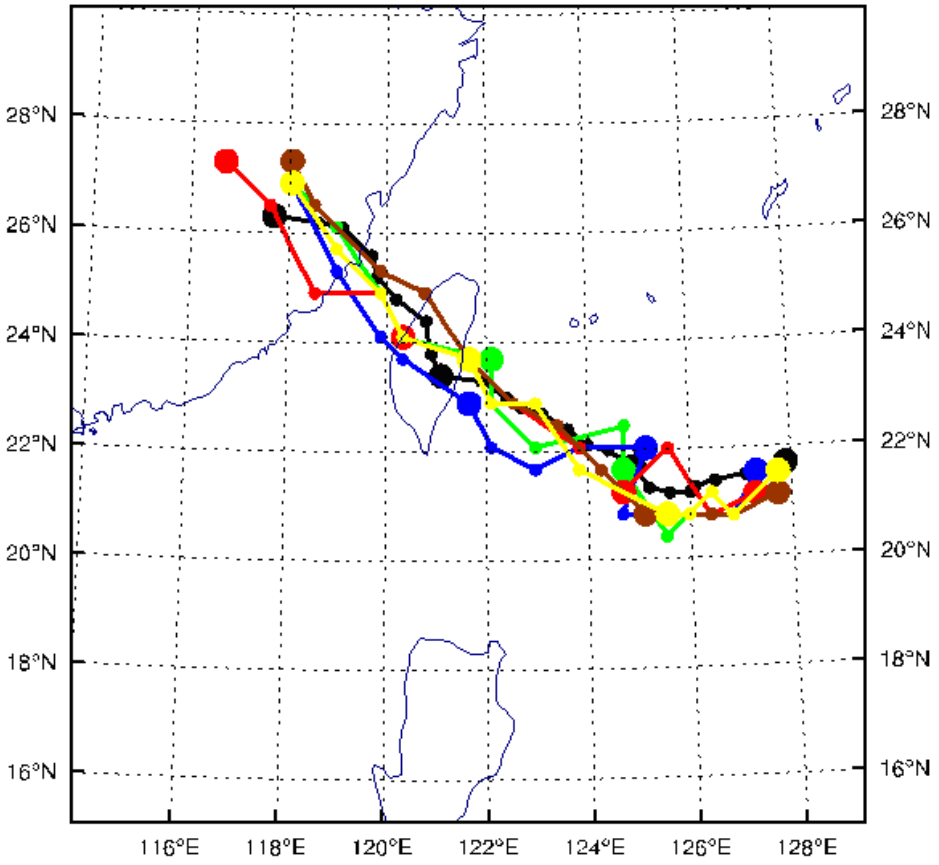


SSM/I

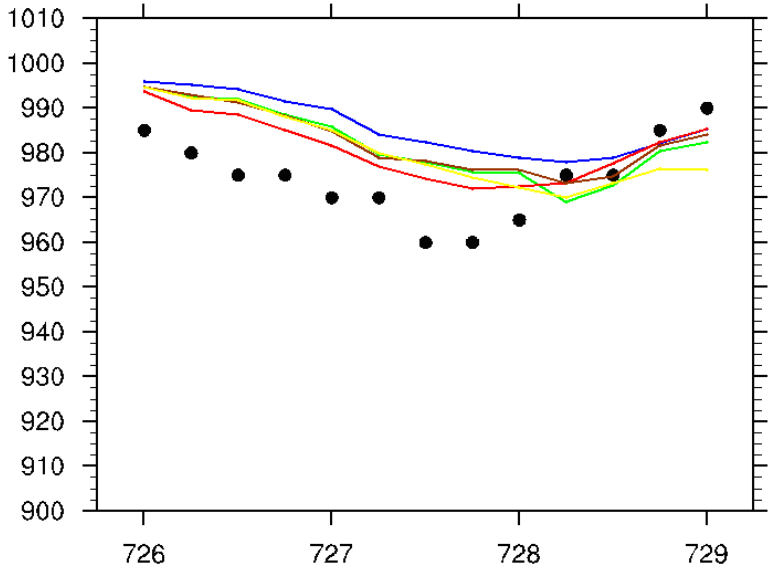


Fung-Wong (2008/0726)

~ 0000 UTC 26 July 2008 for 72 h



- BTrack ip
- None
- Dropsonde (7 points)
- GPS (43 points)
- GTS (with QuikSCAT data)
- SSM/I



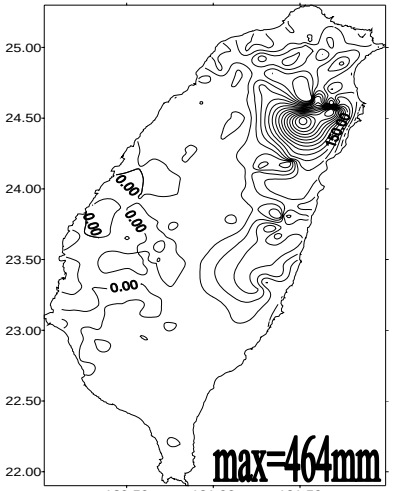
Int:30 mm

2nd day

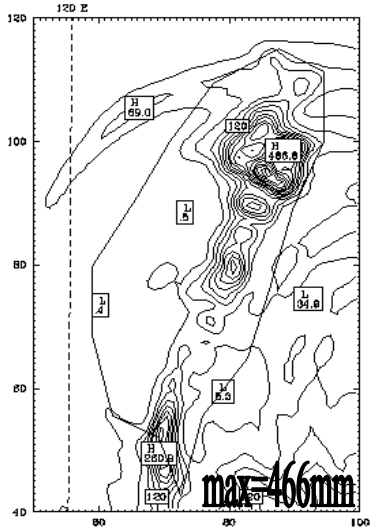
Fung-Wong

WRF simulated 24-h accumulated rainfall (mm) (0727 0000 – 0728 0000 UTC)

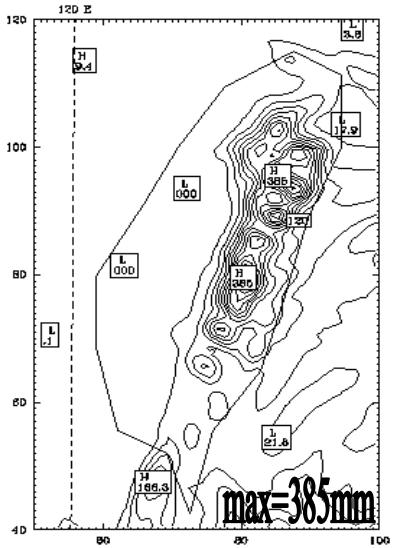
OBS



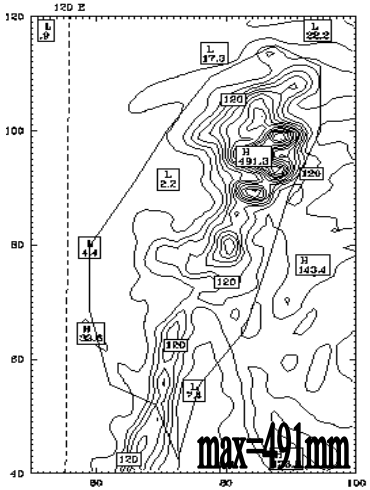
None



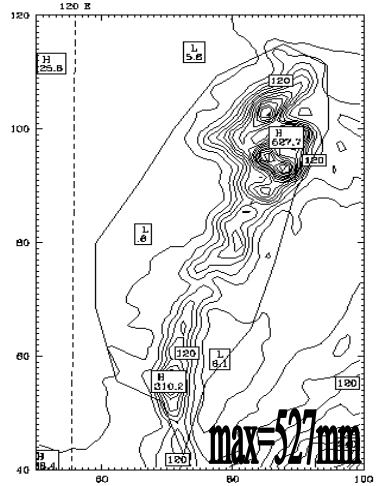
GPS



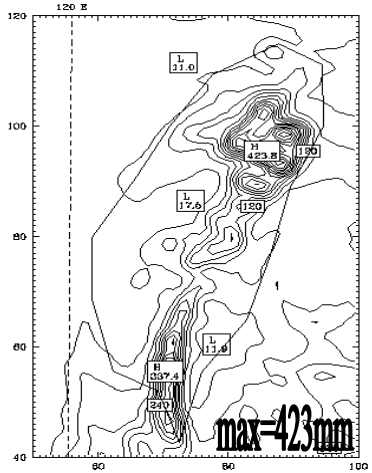
GTS



Drop



SSM/I

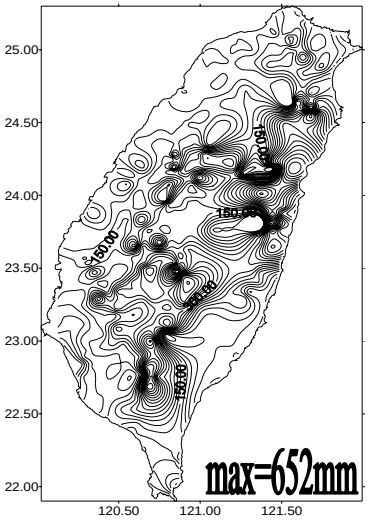


Fung-Wong

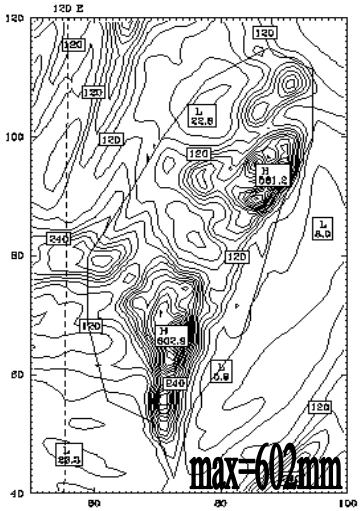
Int:30 mm **3rd day**

WRF simulated 24-h accumulated rainfall (mm) (0728 0000 – 0729 0000 UTC)

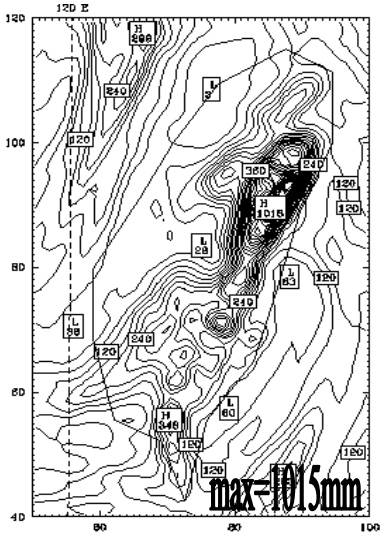
OBS



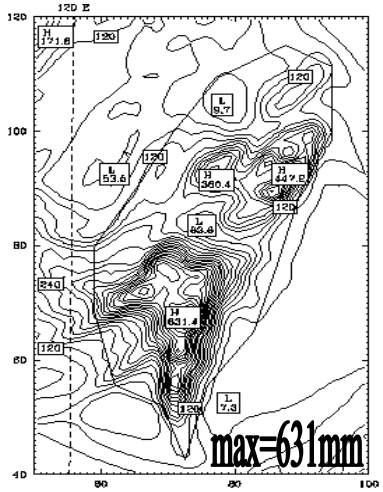
None



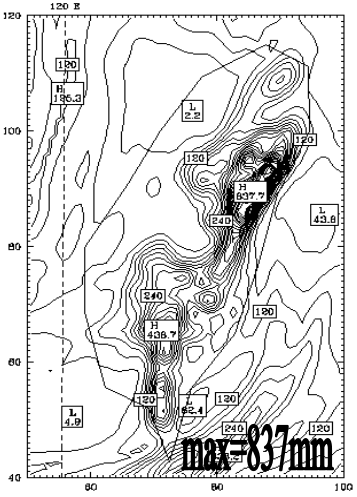
GPS



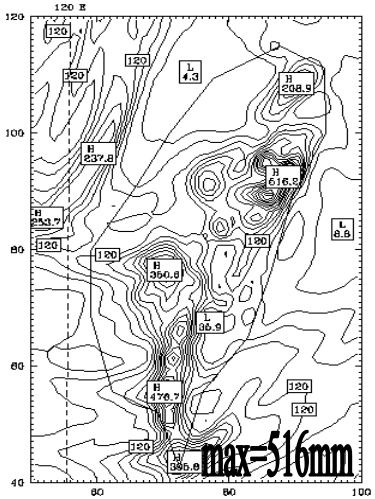
GTS



Drop

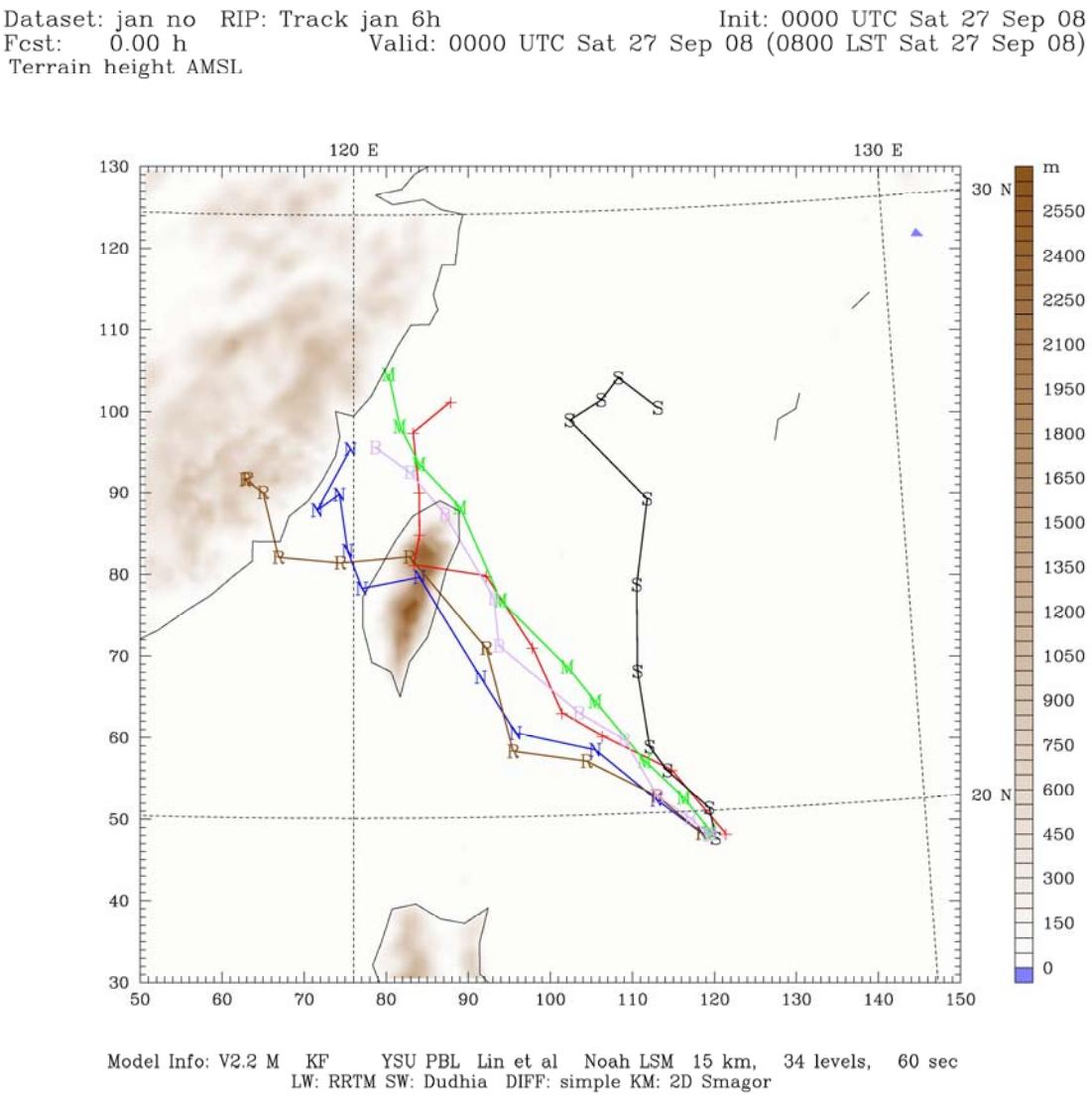


SSM/I



Typhoon Jangmi - 0000UTC 27 Sept. 2008

Descriptions of the numerical experiments	
Experiments	*Assimilated data*
NONE	No data assimilated。
EPH	Used cv options 3 as background error (BE) and GPS data by using nonlocal operator。
EPH+TCBOG_S	Same as experiment EPH, but typhoon bogus vortex is also Assimilated (ROUT=300 km, R34=150 km)。
EPH+TCBOG_M	Same as experiment EPH, but typhoon bogus vortex is also Assimilated (ROUT=500 km, R34=280 km)。
EPH+TCBOG_B	Same as experiment EPH, but typhoon bogus vortex is also Assimilated (ROUT=600 km, R34=300 km)。



N : None

R : EPH (27 points)

S : EPH+TCBOG_S

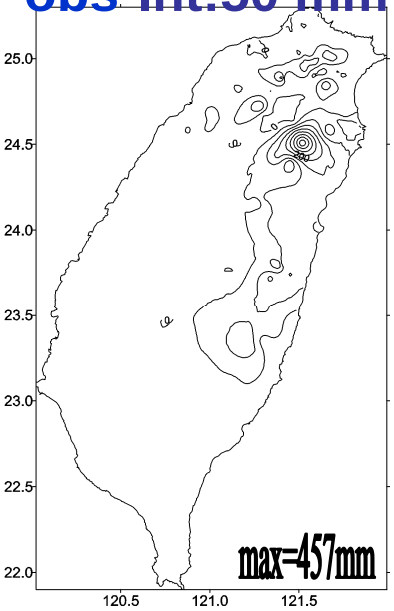
M : EPH+TCBOG_M

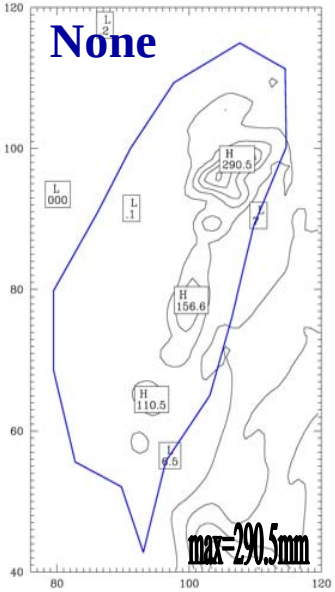
B : EPH+TCBOG_B

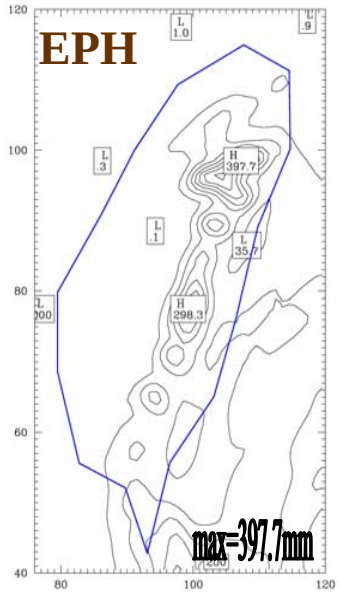
+ : Best track

Intense Typhoon Jangmi- 0000UTC 27 September 2008

Jangmi –2008/09



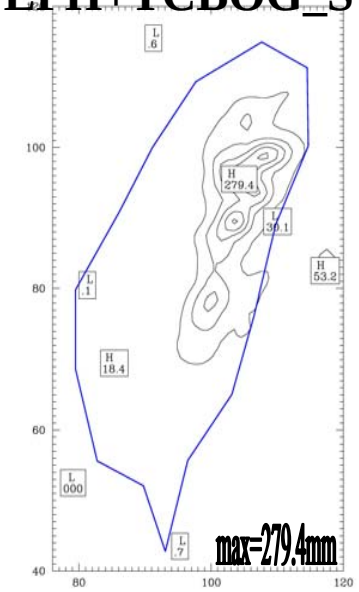




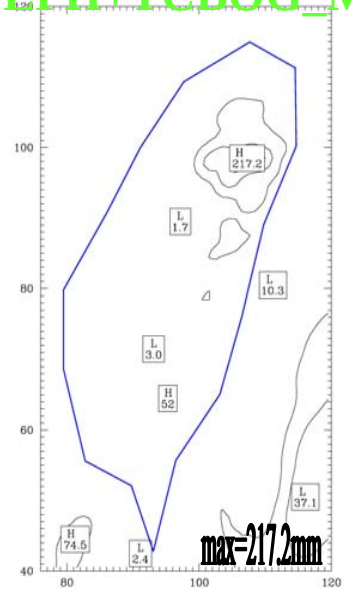
WRF simulated 24-h accumulated rainfall (mm)
(0927 0000 – 0928 0000 UTC)

1st day

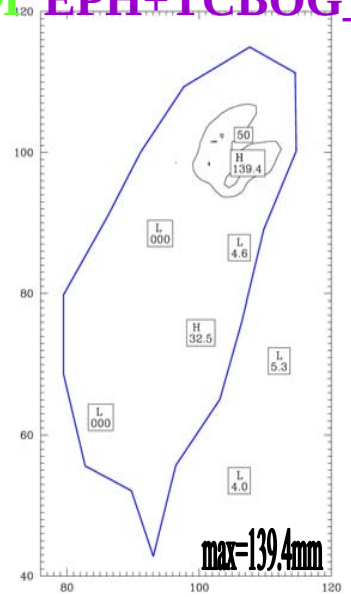
EPH+TCBOG_S



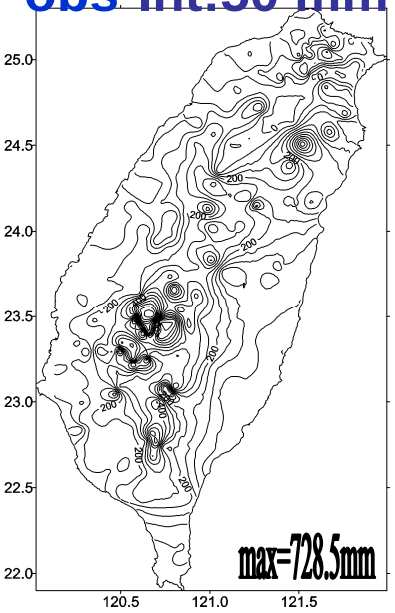
EPH+TCBOG_M

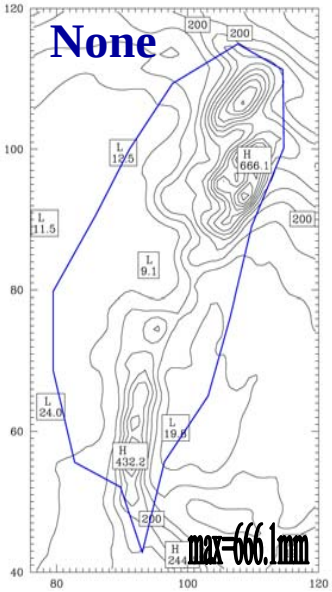


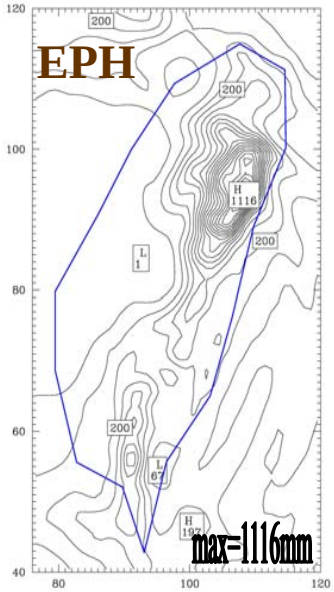
EPH+TCBOG_B



Jangmi –2008/09



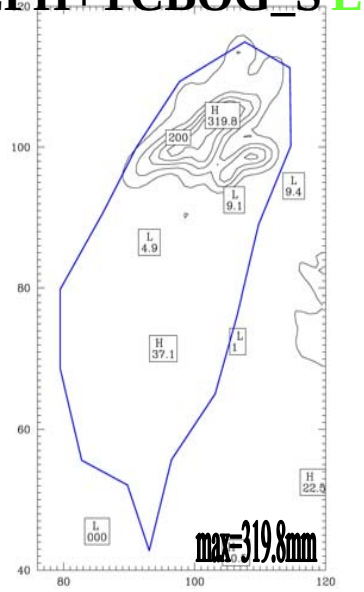




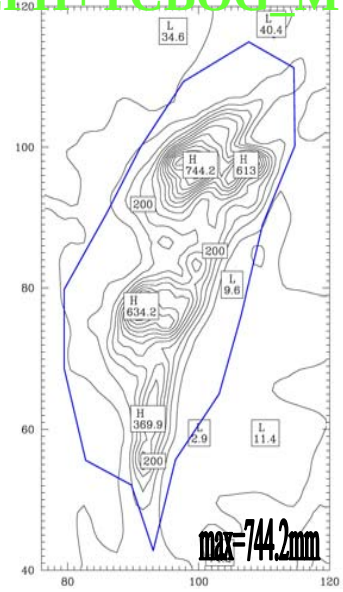
WRF simulated 24-h accumulated rainfall (mm)
(0928 0000 – 0929 0000 UTC)

2nd day

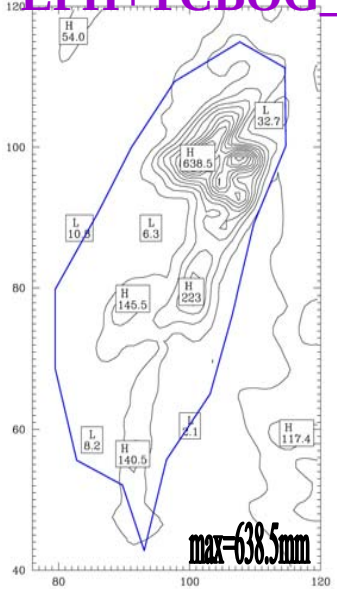
EPH+TCBOG_S



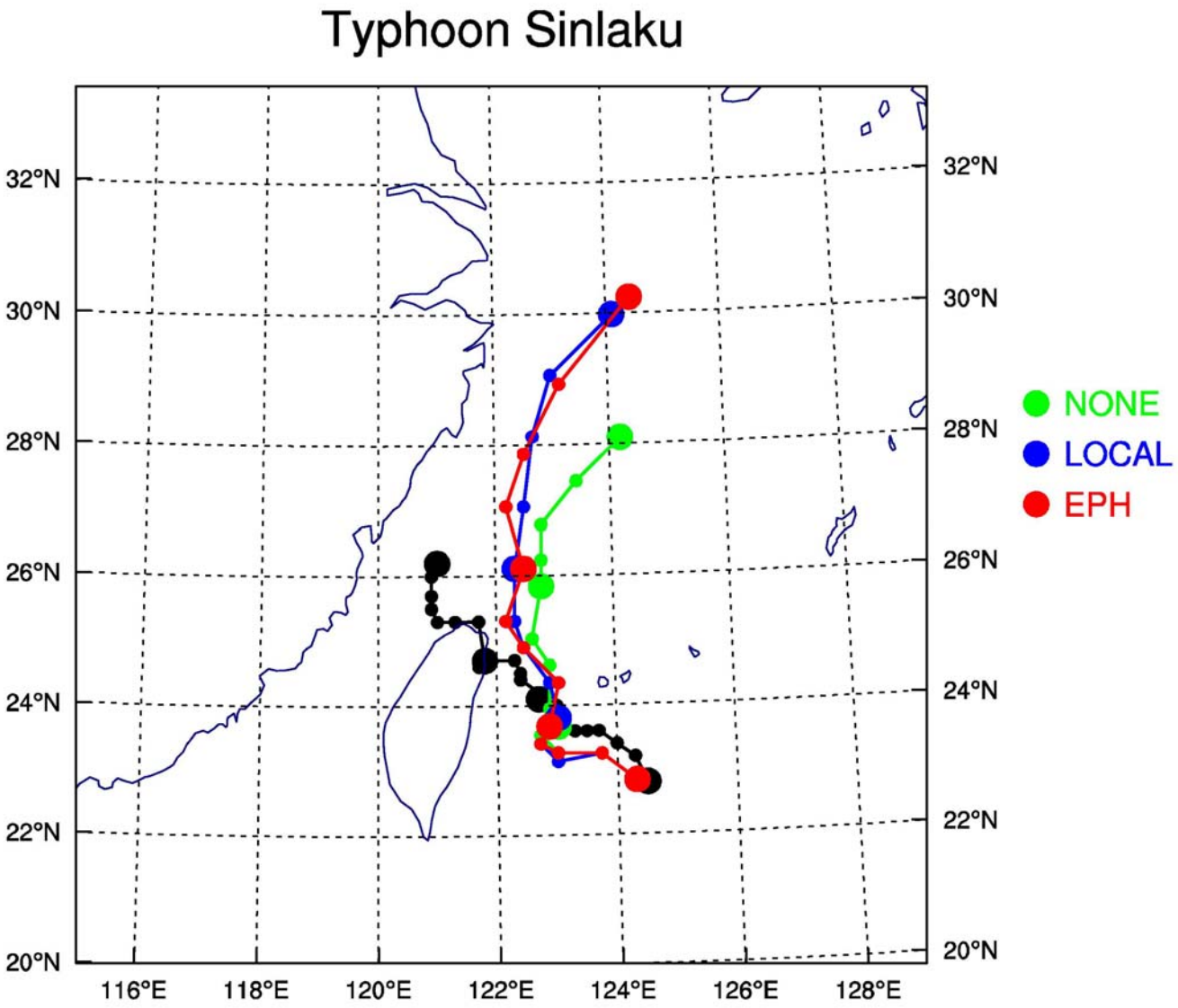
EPH+TCBOG_M



EPH+TCBOG_B

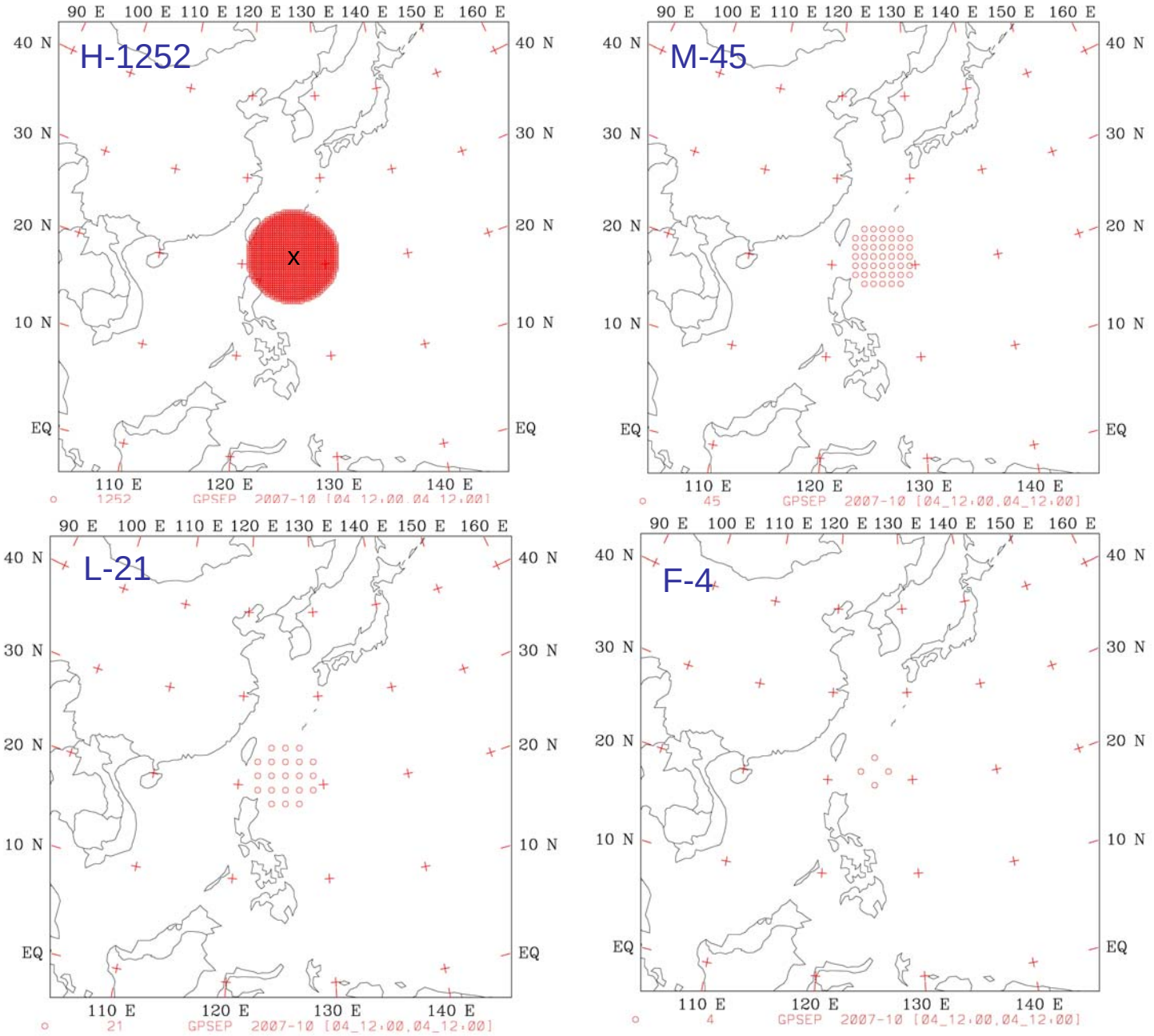


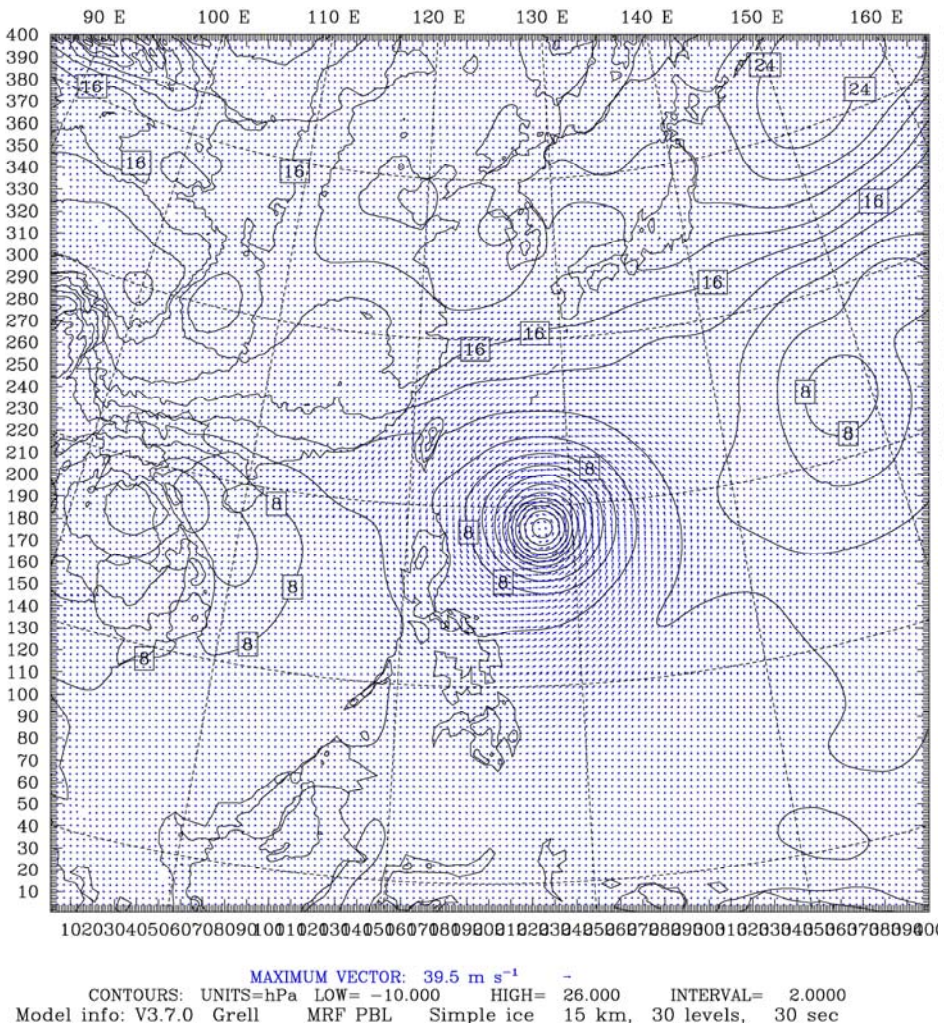
Typhoon Sinlaku - 0000UTC 11 Sept. 2008

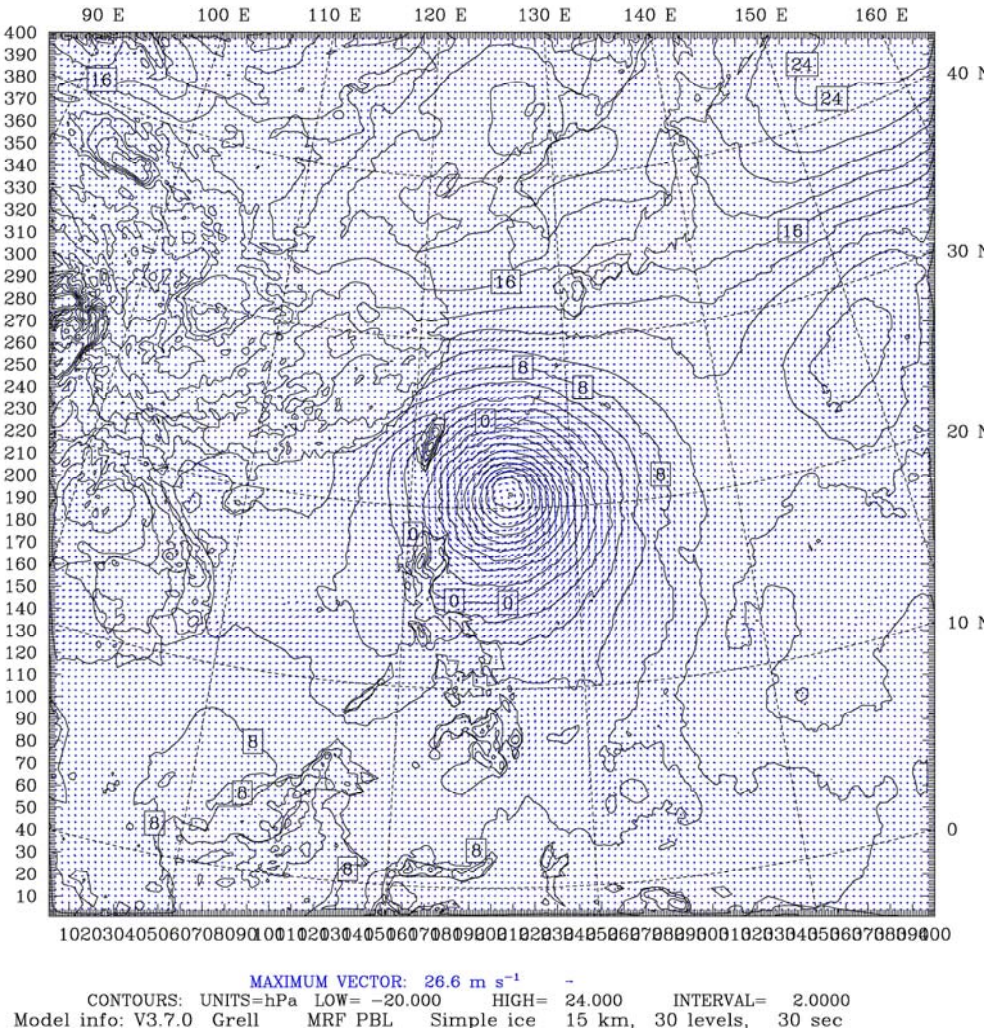


An OSSE Study for Typhoon Krosa

- Perform 96-h MM5 simulation (400x400, 15 km resolution) with an initial Rankine vortex at 0400 Oct. 2007, served as the nature run.
- Retrieve RO soundings by running a 2-D ray-tracing model with the input of the nature run to obtain bending angles (assuming uniform 45^{o} azimuthal angle) and the inverted RO refractivity in the region of the typhoon vortex circulation at 0412 Oct. 2007.
- Perform a linear filter to smooth the nature run at 0412 Oct. 2007 to provide the control run (as the first guess at coarser resolution)
- Perform WRF 3DVAR to assimilate the RO refractivity soundings (model local or retrieved) using the nonlocal operator and local operators at 041200 Oct. 2007.
- Compare the assimilation runs and control run with the nature run.


H-1252
M-45
L-21
F-4
90 E 100 E 110 E 120 E 130 E 140 E 150 E 160 E
40 N
30 N
20 N
10 N
EQ
110 E 120 E 130 E 140 E
1252 GPSEP 2007-10 [04_12:00,04_12:00]
45 GPSEP 2007-10 [04_12:00,04_12:00]
21 GPSEP 2007-10 [04_12:00,04_12:00]
4 GPSEP 2007-10 [04_12:00,04_12:00]

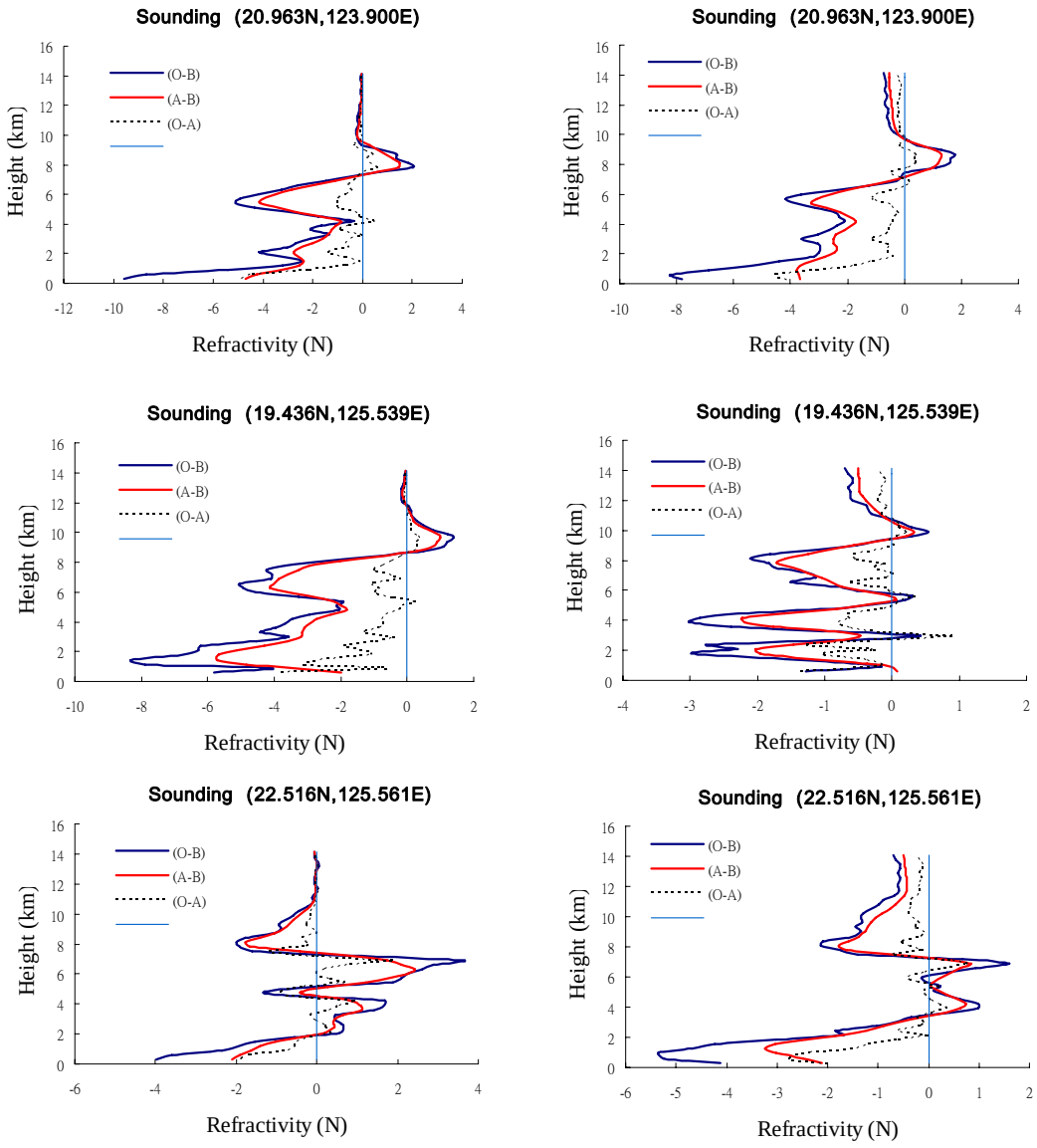




Nature run at 0000UTC 04

Nature run at 1200UTC 04

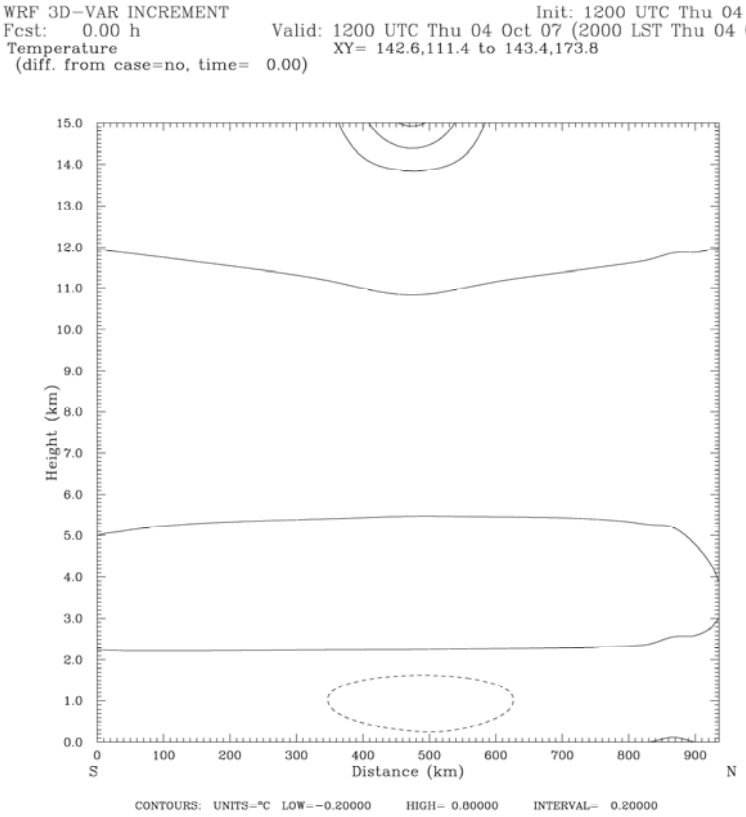
Experiments	Remarks
NTR	MM5 initialized with AVN analysis and a Rankine vortex of 200-km radius at 2007100400UTC at 15-km resolution. The model results at 2007100412UTC are used as the initial atmospheric state of a 2-D raytracing model which generates the GPS RO refractivity observations from the Abel inversion of the simulated bending angles.
CTL	Degraded NTR and the vortex circulation at 2007100412UTC to mimic the large-scale analysis.
LM_h	As CTL but assimilating hypothetically high (1252) model local refractivity soundings (30-km resolution) surrounding the vortex center in the vortex using the local operator (on obs.)
LR_h	As CTL but assimilating hypothetically high (1252) retrieved refractivity soundings (30-km resolution) surrounding the vortex center using the local operator (on obs.)
NR_x (x=h, m, l, f)	As CTL but assimilating retrieved refractivity soundings surrounding the vortex center using the localized nonlocal operator, where h, m, l and f indicate 1252, 45, 21 and 4 soundings, respectively.
NE_x (x=h, m, l, f)	As CTL but assimilating excess phase (EPH) soundings (30-km resolution) surrounding the vortex center using the nonlocal operator



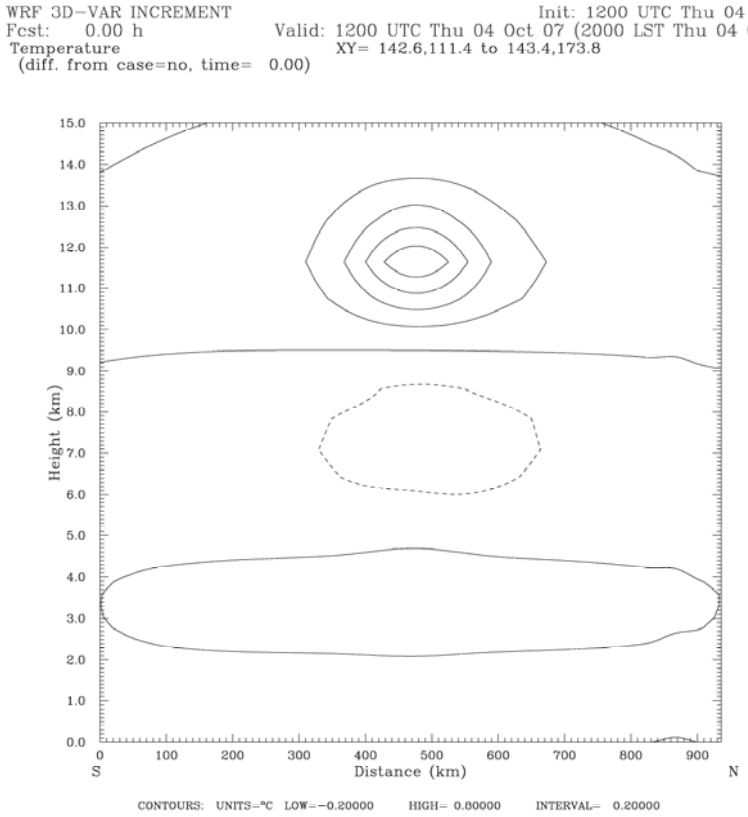
With Model-N **With Retrieved-N**

FIG. Vertical profiles of the (O-B), (O-A) and (A-B) for West, South, North points of F-case where the observations (O) are from the nature run and the background field (B) uses the model initial condition of the control run and the analysis (A) is the result after 3DVAR for (a) the model local refractivity and (b) the retrieved refractivity used as observations.

Temperature increments along N-S cross-section through one sounding point



Model - NTR



Retrieved - NTR

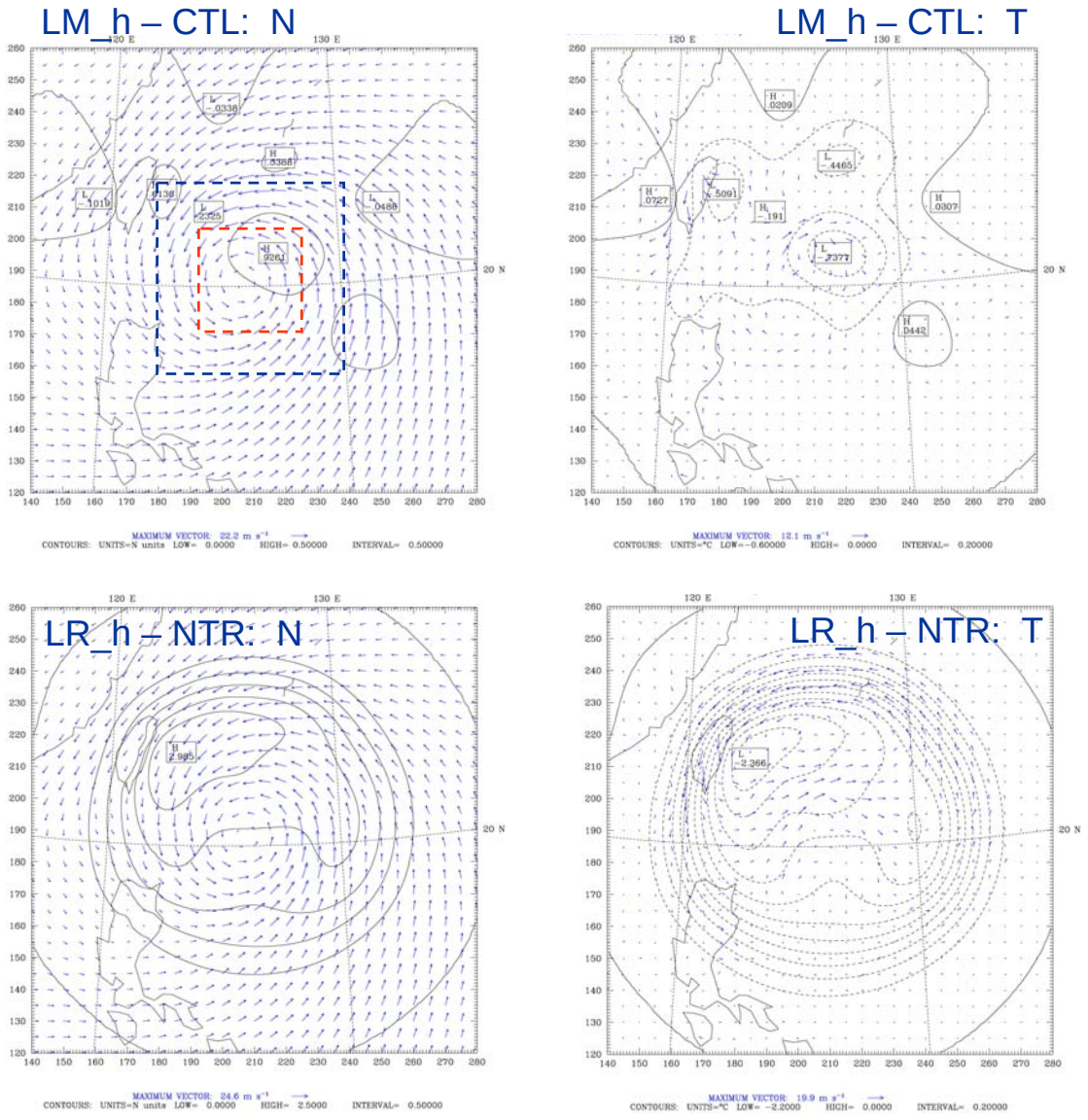


FIG. (a) The initial refractivity increments between LM_h and CTL (control run) and wind for LM_h near the surface (K=30) at 1200 UTC 04 October 2007, (b) as in (a) but for temperature increments at level K=22 (about 860 mb) and wind increments between LM_h and NTR (nature run), (c) and (d) as in (a) and (b), respectively, but between LR_h and NTR.

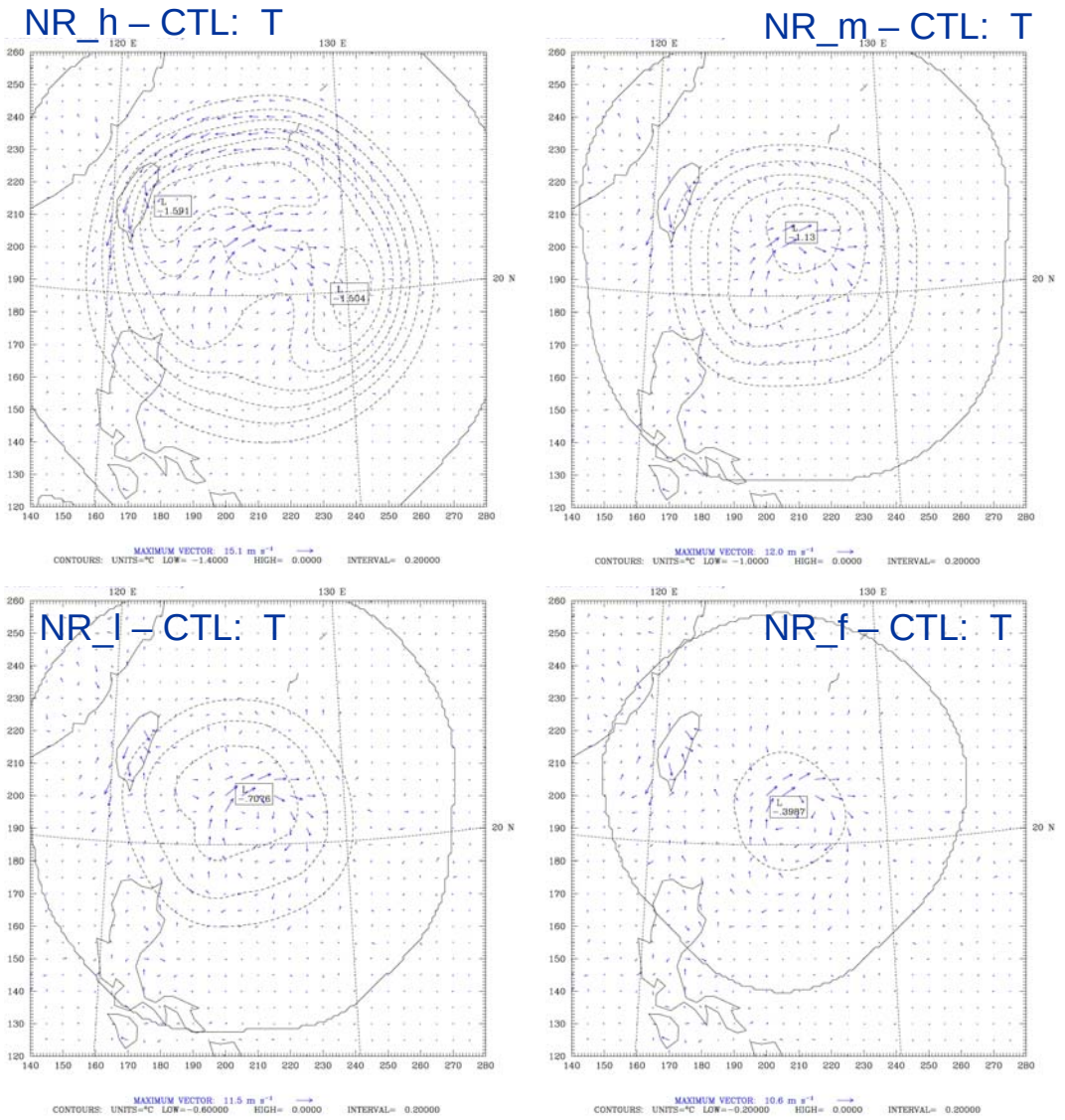


FIG. (a) The initial temperature and wind increments for NR_h from CTL at level K=22 (about 860 mb), 1200 UTC 04 October 2007, and for (b) NR_m, (c) NR_l, and (d) NR_f.

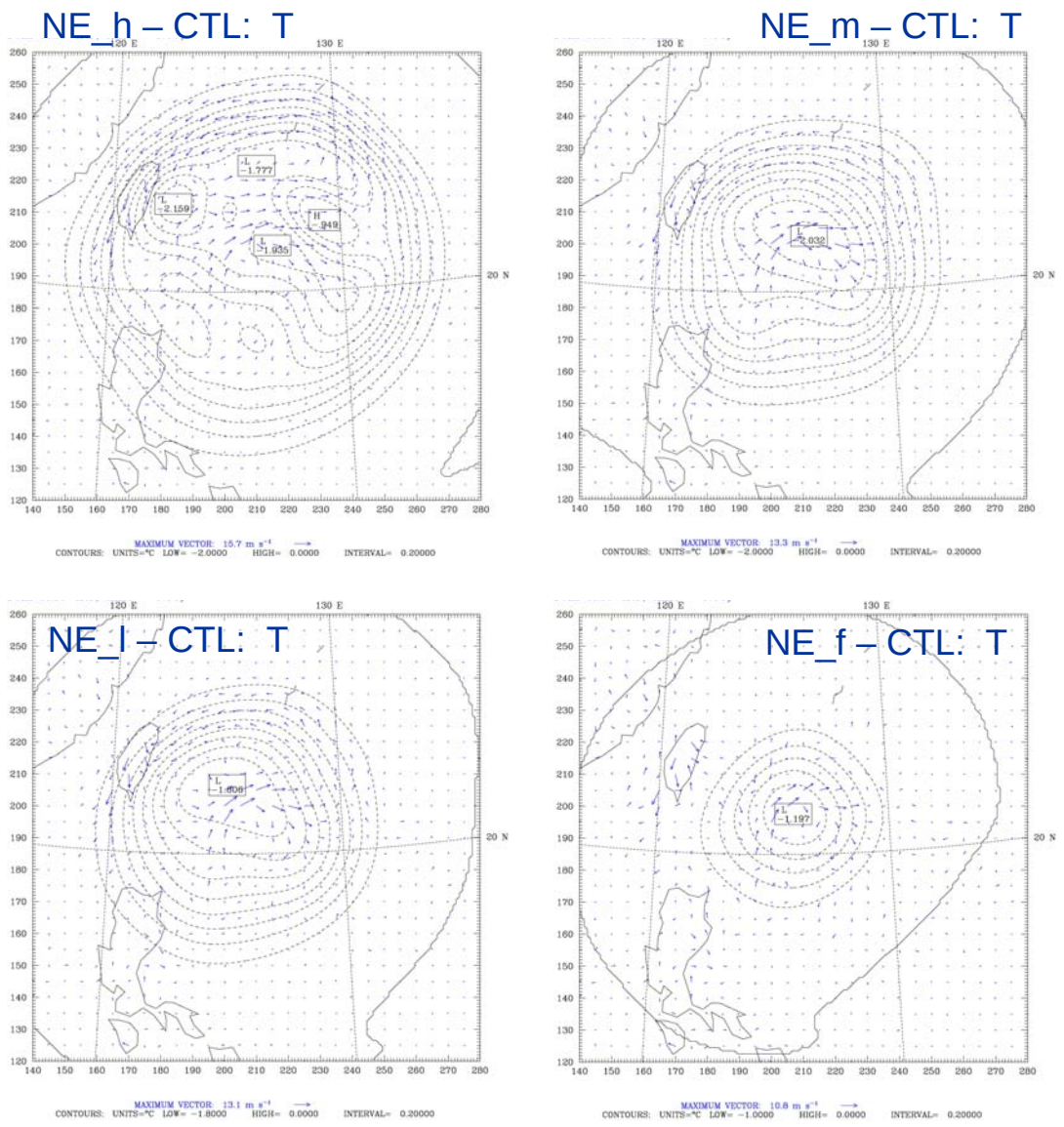


FIG. (a) The initial temperature and wind increments for NE_h from CTL at level K=22 (about 860 mb), 1200 UTC 04 October 2007, and for (b) NE_m, (c) NE_l, and (d) NE_f.

From NTR	U (m/s)	V (m/s)	T (K)	Q (g/kg)	N (unit)
CTL	1.46 / 2.39	1.48 / 2.48	0.62 / 0.50	0.52 / 0.49	1.42 / 1.51
LM_h	1.74 / 2.89	1.84 / 3.07	0.63 / 0.52	**0.50 / 0.39**	**1.31 / 0.94**
LR_h	6.60 / 6.97	6.31 / 5.18	0.93 / 1.38	0.53 / 0.52	1.59 / 1.97
NR_h	6.61 / 6.97	6.39 / 5.52	0.83 / 1.14	0.61 / 0.79	1.52 / 1.76
NE_h	7.25 / 7.32	6.82 / 5.07	0.91 / 1.25	0.63 / 0.82	1.76 / 2.32
NR_m	3.73 / 6.27	3.62 / 5.99	0.68 / 0.78	0.54 / 0.62	1.42 / 1.49
NE_m	5.23 / 8.41	5.03 / 7.82	0.77 / 1.10	0.56 / 0.65	1.51 / 1.88
NR_l	2.67 / 4.41	2.64 / 4.27	0.65 / 0.63	0.53 / 0.54	1.42 / 1.50
NE_l	4.64 / 7.52	4.49 / 7.12	0.74 / 0.99	0.54 / 0.60	1.47 / 1.73
NR_f	1.60 / 2.75	1.61 / 2.76	0.62 / 0.51	0.52 / 0.49	1.42 / 1.50
NE_f	2.41 / 4.69	2.33 / 4.46	0.64 / 0.61	0.52 / 0.50	1.43 / 1.56

RMSE:
Larger zone/
Smaller zone
around the vortex

← Better Q, N, not U,V,T

← Worse for high_R !!

← Better NR than NE

← Better NR than NE

← Better NR than NE

← Better NR than NE

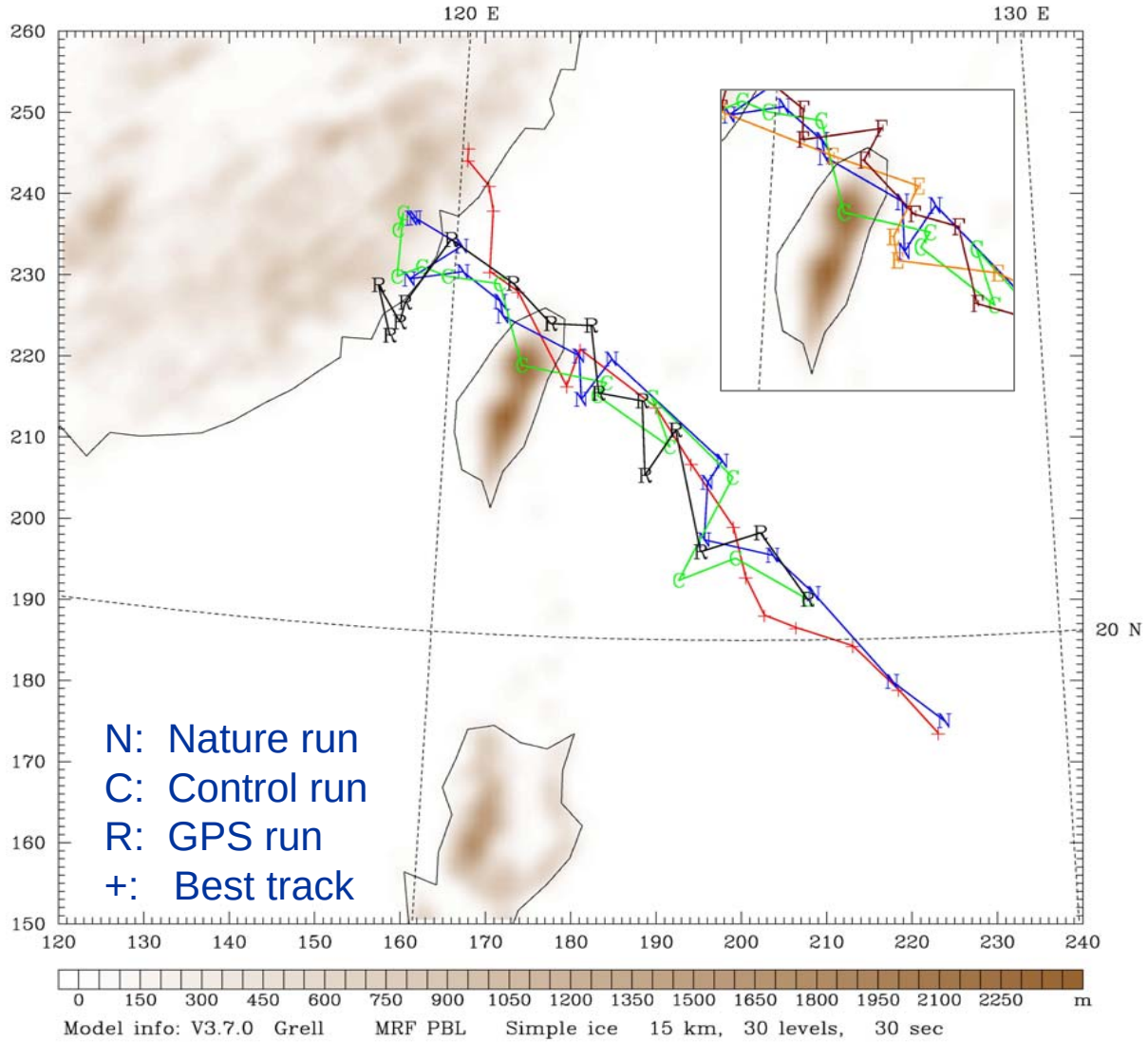


FIG. The real best track (+) of Typhoon Krosa (2007), the simulated tracks of the nature run NTR (denoted by N), the control run CTL (C), and the assimilation runs LR_h using the local operator (R), NE_h using the nonlocal operator (E), and NE_m using the nonlocal operator (F).

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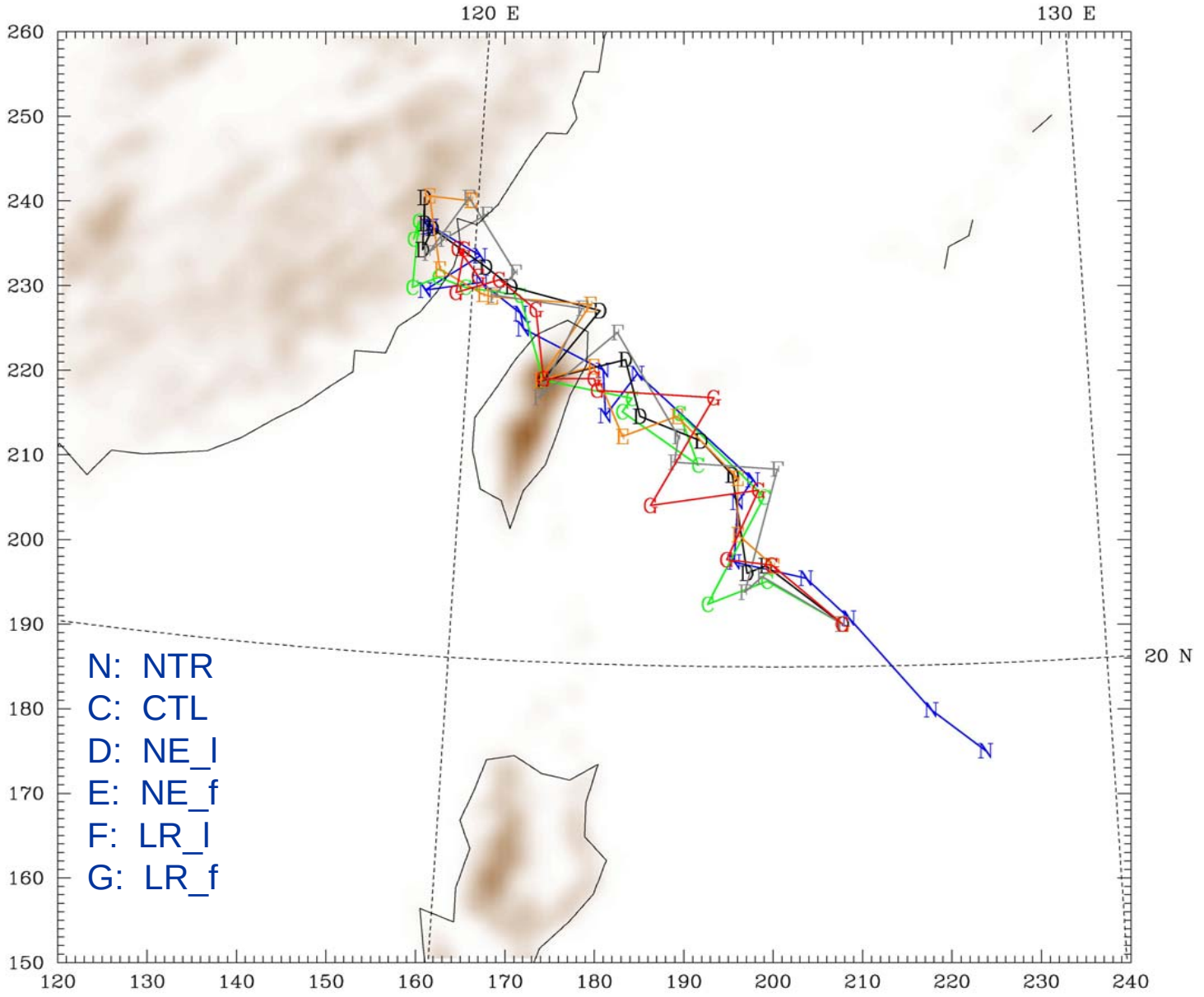
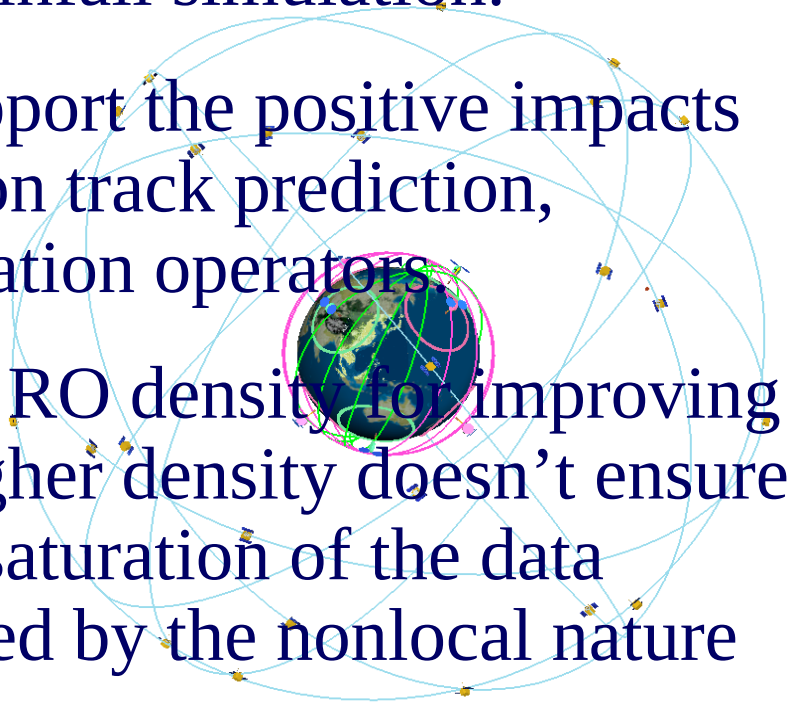


Both tracks of simulations with 21 and 4 RO points are similar

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. Some positive impacts are also found for Mei-yu front rainfall simulation.
- The OSSE studies tend to support the positive impacts of the GPS RO data on typhoon track prediction, regardless of different assimilation operators.
- There might exists an optimal RO density for improving typhoon prediction. Much higher density doesn't ensure further improvement, due to saturation of the data information that can be exposed by the nonlocal nature of refractivity.



Thanks for your attention.