Assimilation of GPS RO Data for Typhoon Prediction

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Central Weather Bureau, Taipei, 30 May – 3 June, 2005

CASE SIMULATIONS WITH RO DATA:

2001- Typhoon Lekima、
2001- Typhoon Nari、
2002- Typhoon Nakri、
2002- Typhoon Sinlaku、
2003- Dujuan Typhoon (2003/08/31/12-09/02/00)
2004- Cold front-1 (2004/02/06/18)
2004- Cold front-2 (2004/02/07/06)
2004- Meiyu front (2004/05/19/12-22/12)
2004- Conson typhoon (2004/06/07/00-09/00)
2004- Mindulle typhoon (2004/06/29/06-07/02/06)
2004- Aere typhoon (2004/08/21/18-25/12)
2004- Namadol typhoon (2004/12/02-04)
2004- Cold front(2004/12/03 or 06)
2005- Early-March snow event (cold front)*

Model Domain and Physics

- The model simulations use three nested domains at 45-, 15- and 5-km resolutions.
- All the simulations use MM5 version 3.5 with explicit treatments (Goddard's scheme) for ice/graupel physics in the three domains (1, 2 and 3), Anthes Kuo's scheme and Grell's scheme for cumulus parameterization in domain 1 (largest) and domain 2, respectively, and the Blackadar scheme for PBL parameterization in all the domains.
- 3DVAR was performed for each domain with GPSrf.

Covariance Matrix- O

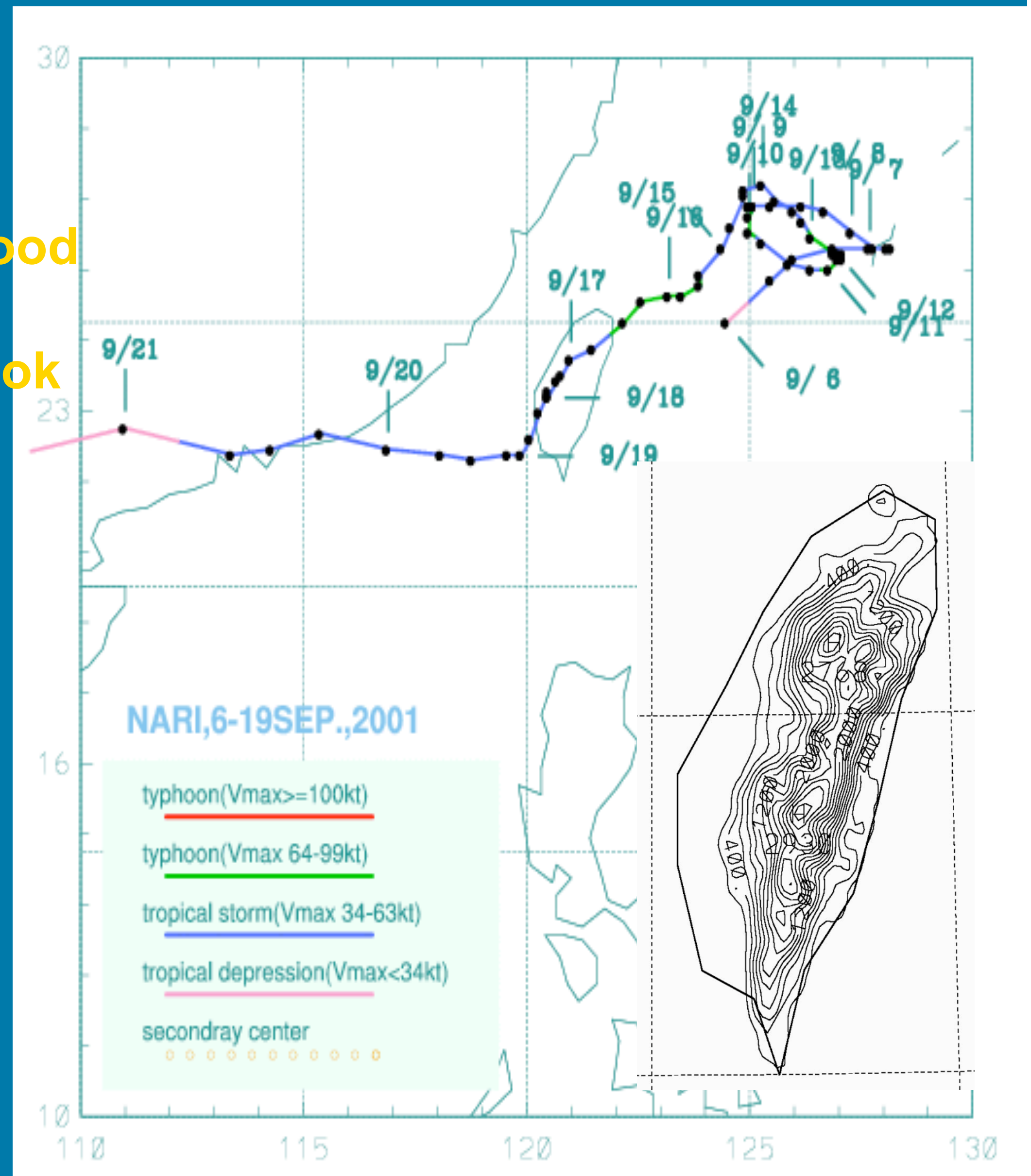
- The GPS radio occultation observational covariance matrix is diagonal and thus has assumed no vertical correlations.

- This assumption of vertical un-correlation is certainly not supportive of some existing dependence between observations, but in absence of statistical information on those correlations, the assumption insures that the data information is not underestimated in assimilation.

- The diagonal elements (variances) are prescribed as a profile exponentially decreasing from 3 N at 100 hPa to 10 N at 1000 hPa. The value of 10 N observational error near the surface is consistent with the 3% refractivity difference between CHAMP radio-occultations and ECMWF analysis found at 1000 hPa, as reported by Kuo et al. (2004).

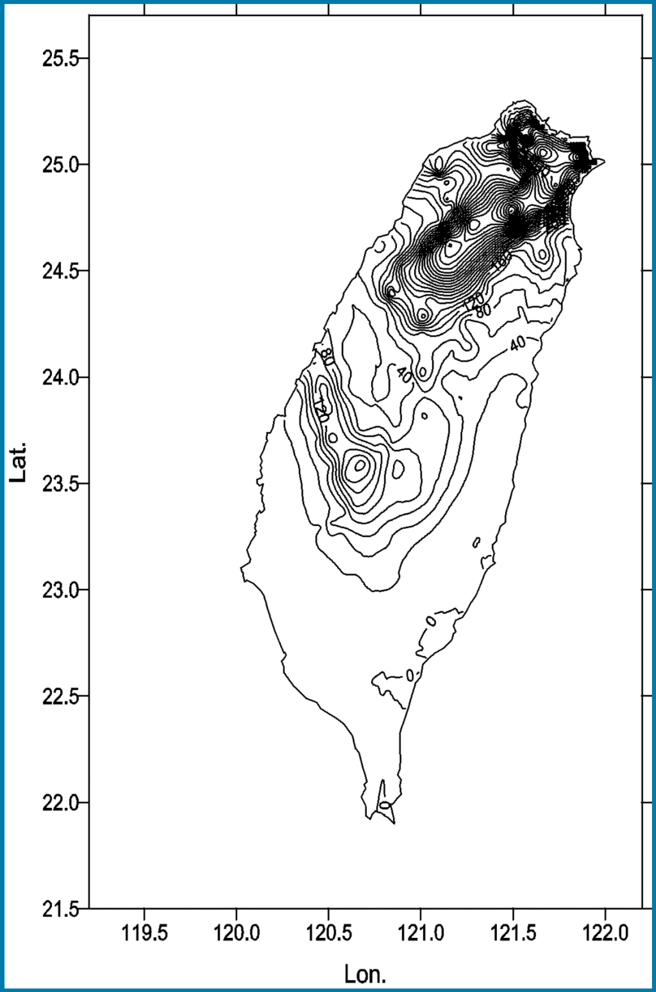
Nari best track (CWB)

- Such a track was observed once per about thirty years.
- Nari made a record-breaking flood in Taipei, causing shutdown of the subway system which took one month to vacate water and clean the facilities, and three months to resume.
- The high topography (CMR) in Taiwan plays a major role in rainfall distributions.

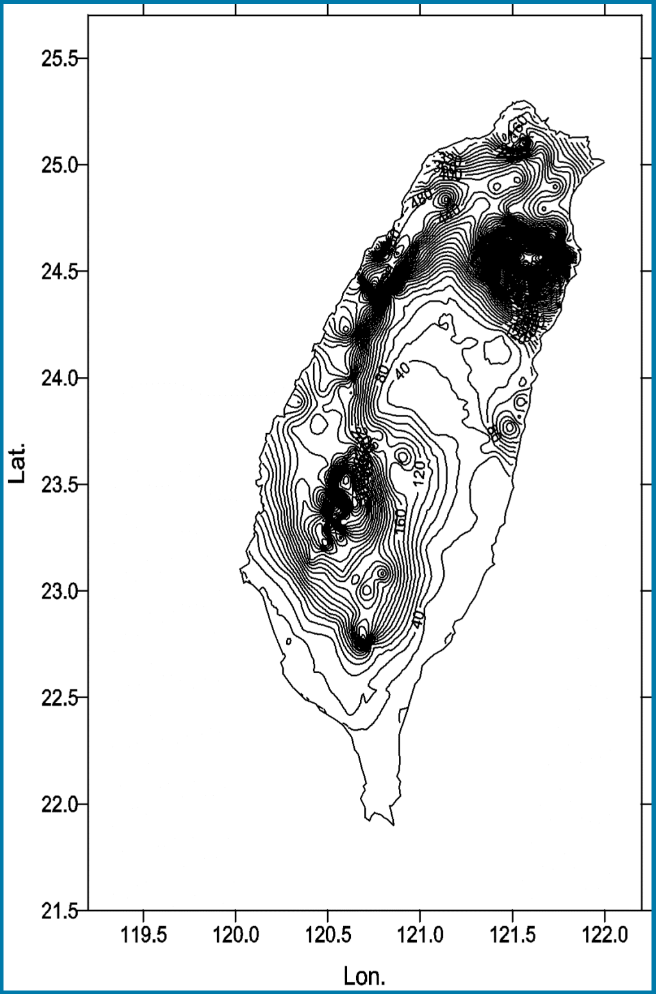


Observed 24-h accumulated rainfall (mm)

Major rainfalls over northern, south-western slopes and I-Lan.



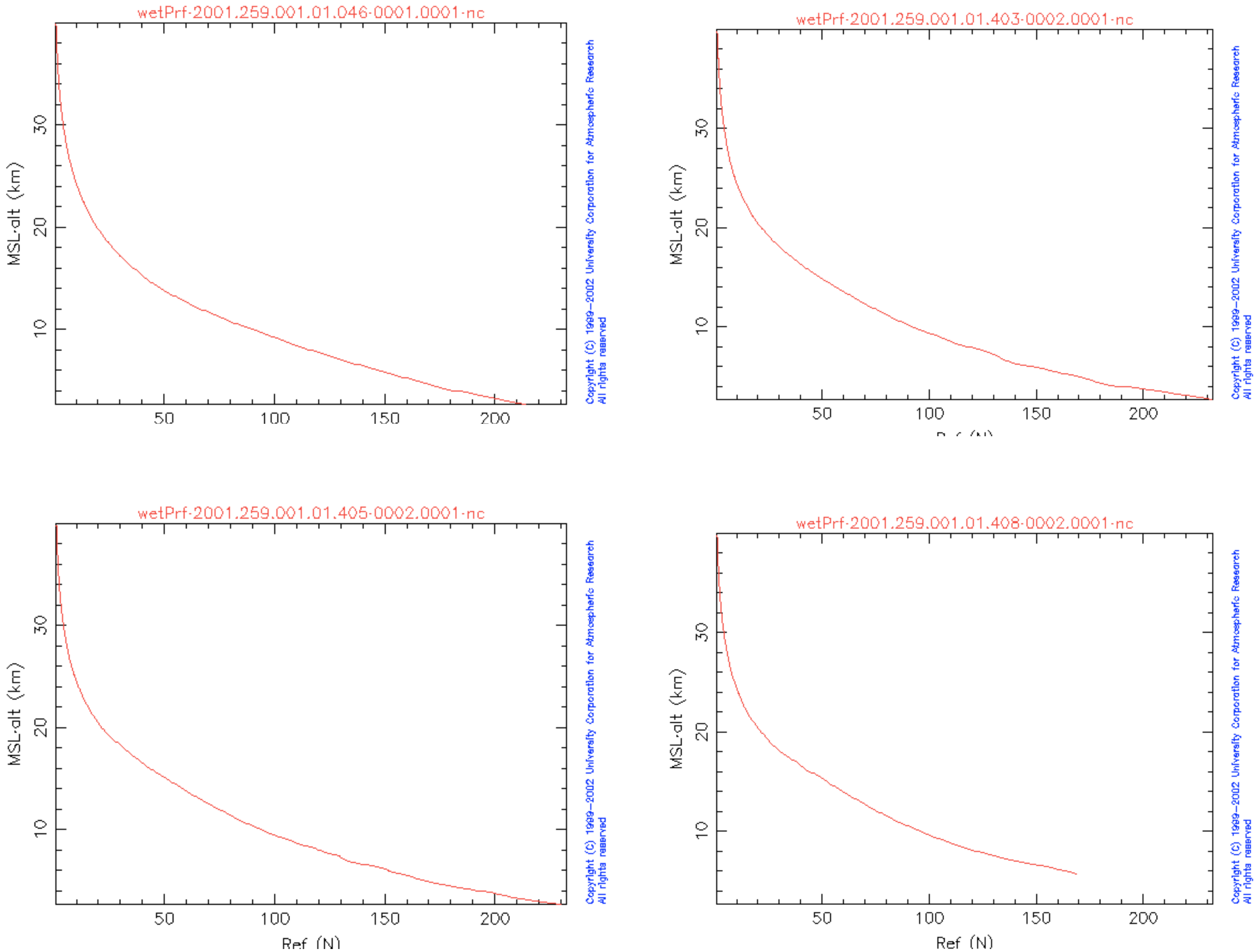
(a) 0000-2400 UTC 16 Sep. 2001
(max value: 712 mm)



(b) 0000-2400 UTC 17 Sep. 2001
(max value: 1144 mm)

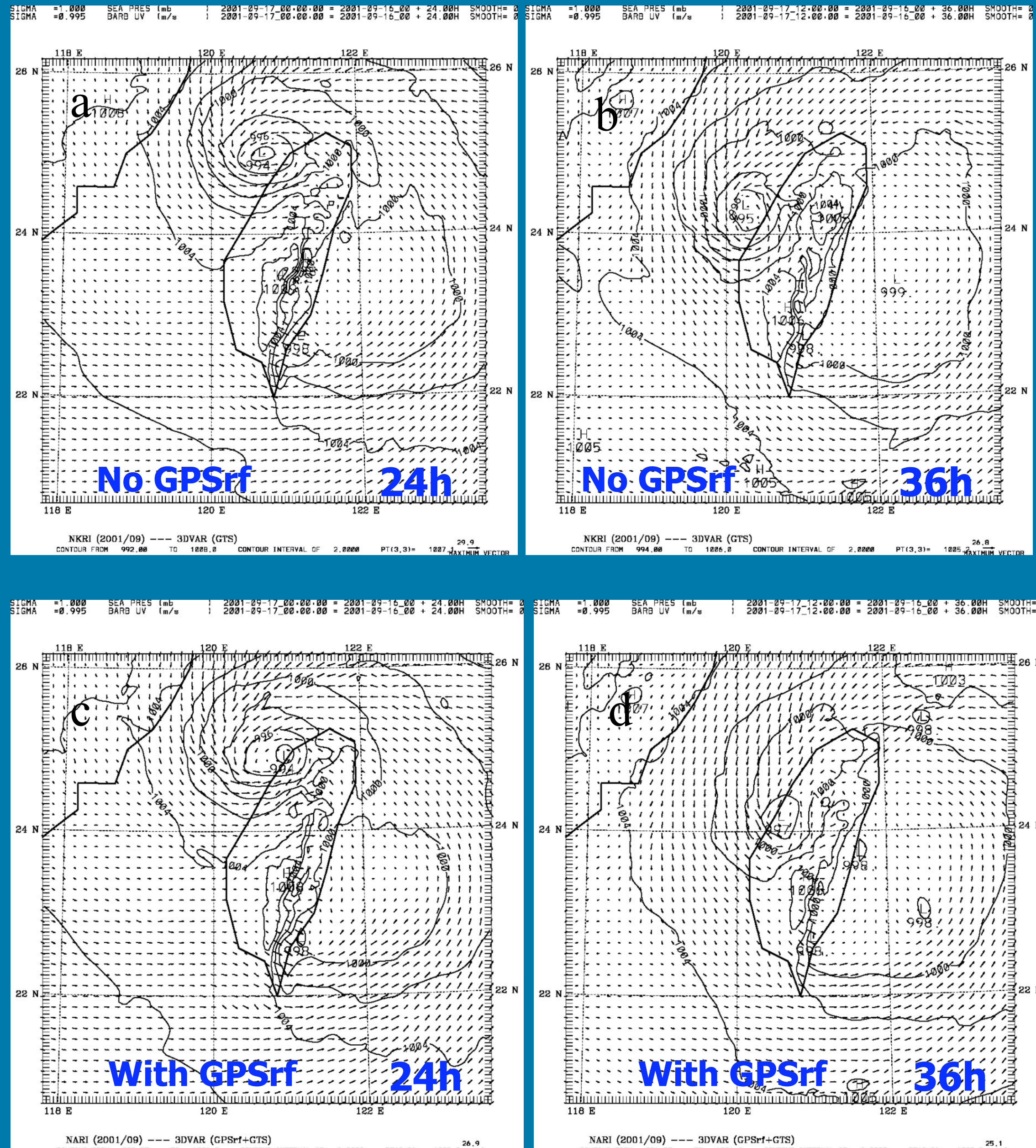
Wetprf.2001.259.001.01.046.0001.0001.nc	01:45am	51.500	154.030
Wetprf.2001.259.001.01.403.0002.0001.nc	02:22am	38.014	140.001
Wetprf.2001.259.001.01.405.0002.0001.nc	02:26am	25.040	136.964
Wetprf.2001.259.001.01.408.0002.0001.nc	02:30am	4.185	136.568

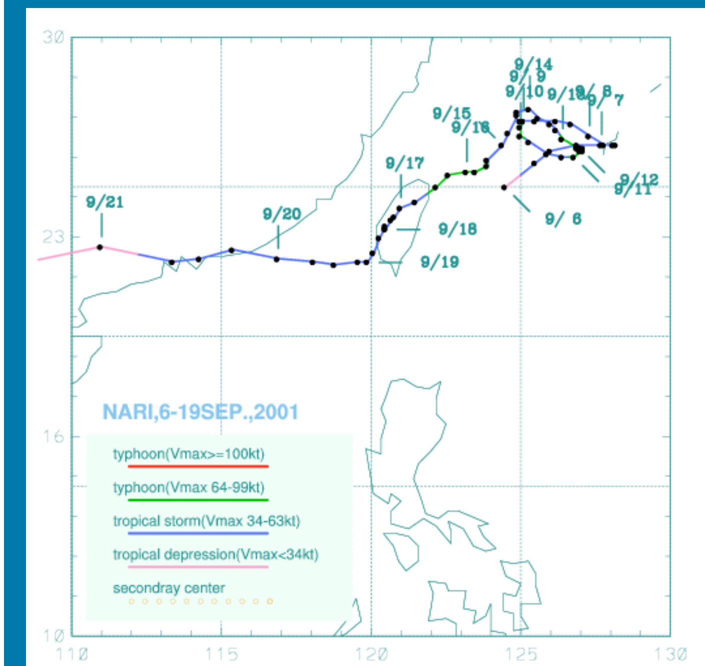
Domain-1 (45-km Grid)



2001/09
Nari Typhoon

MM5 simulated near-surface pressure (mb) and wind (ms^{-1}) at 24h, 36h.

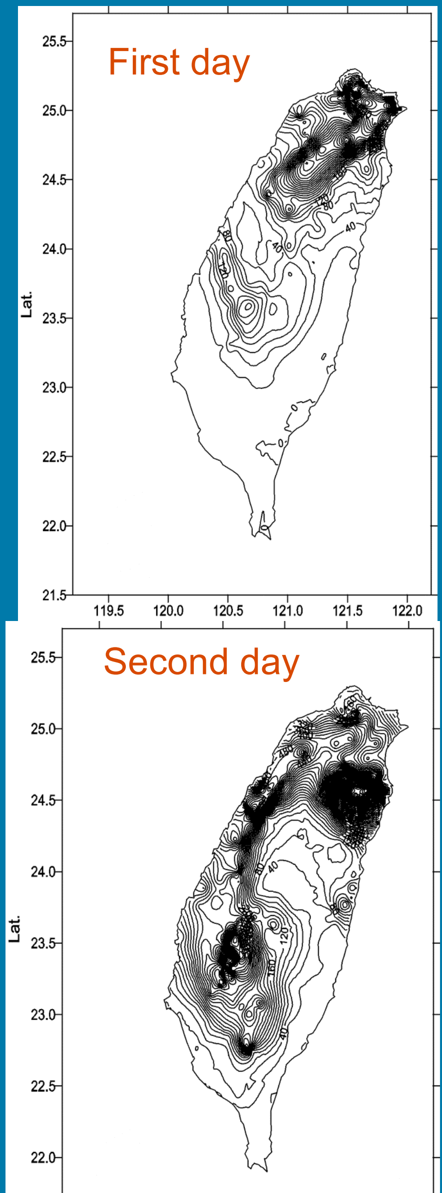




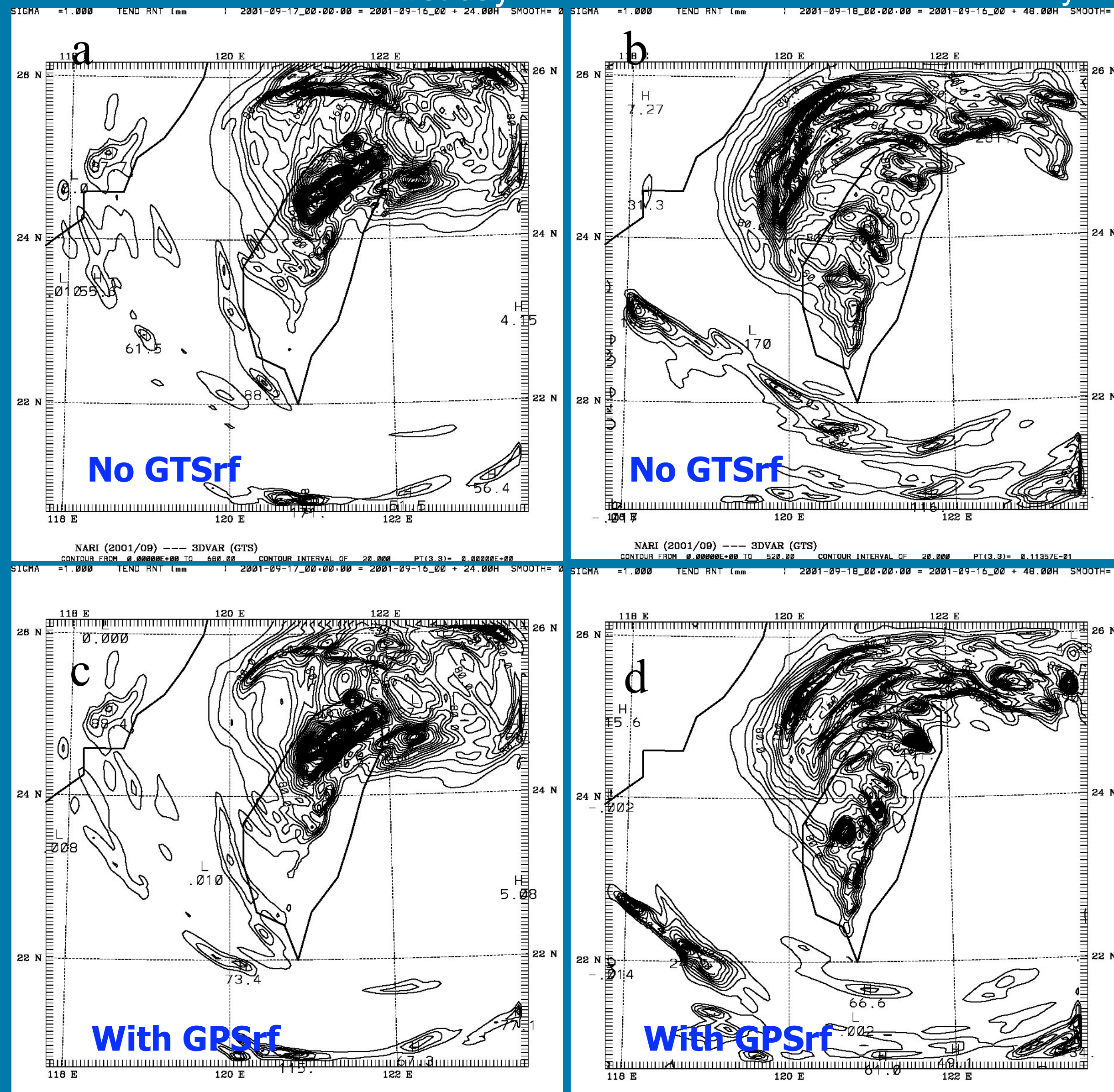
- ➢ **The track is closer to the best track, with GPSrf assimilated.**

2001 Nari Typhoon

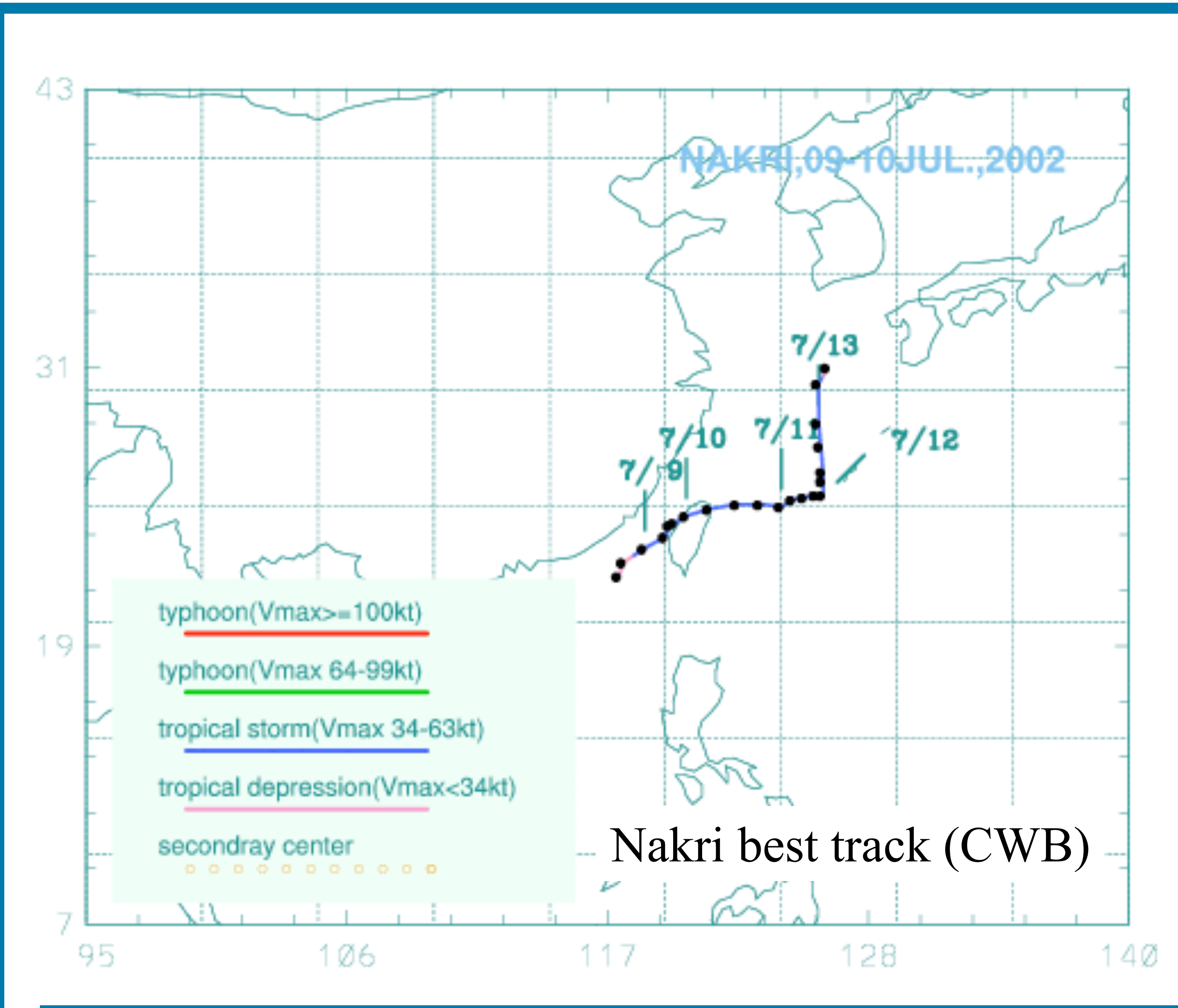
MM5 simulated 24-h accumulated rainfall (mm)



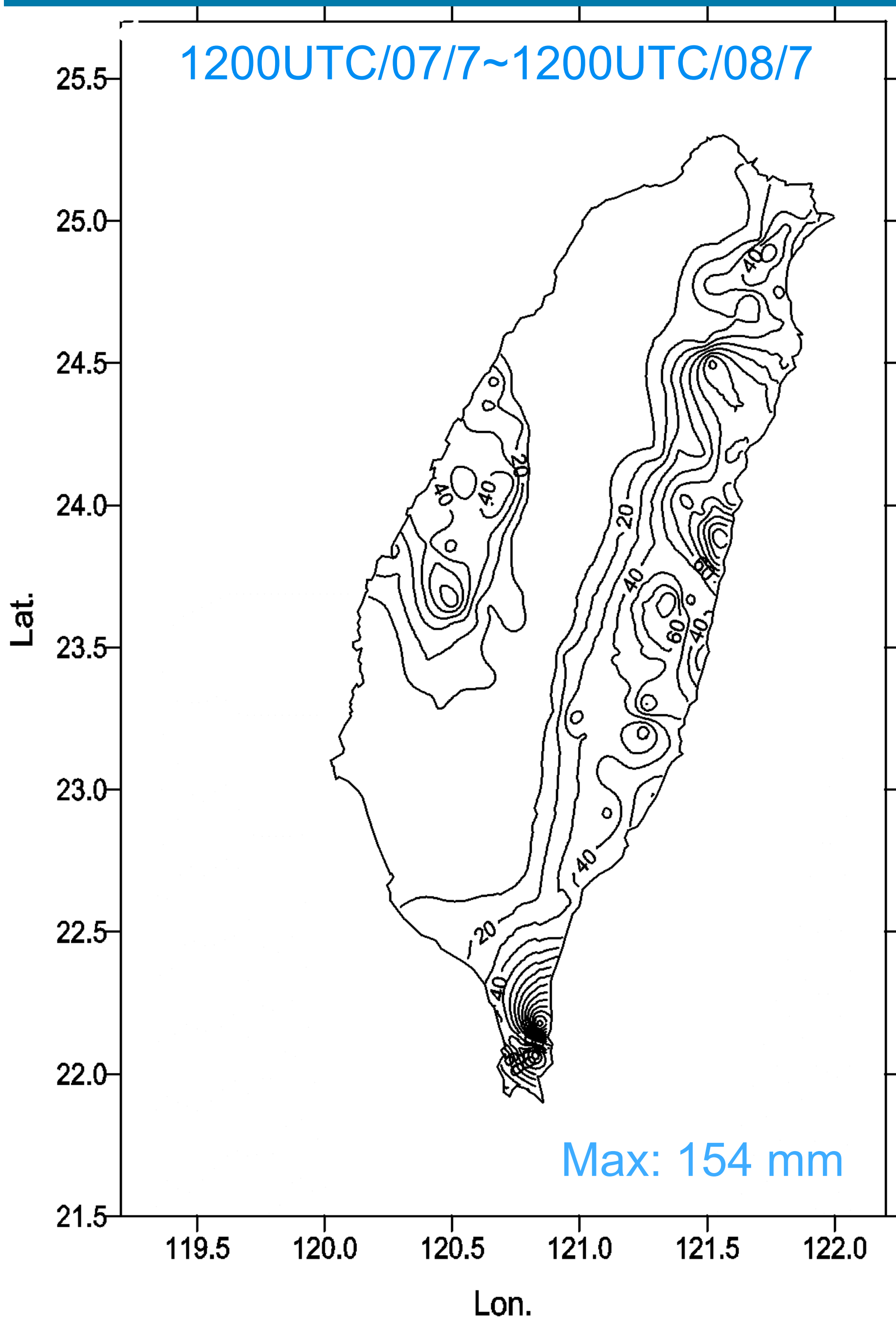
First day | Second day

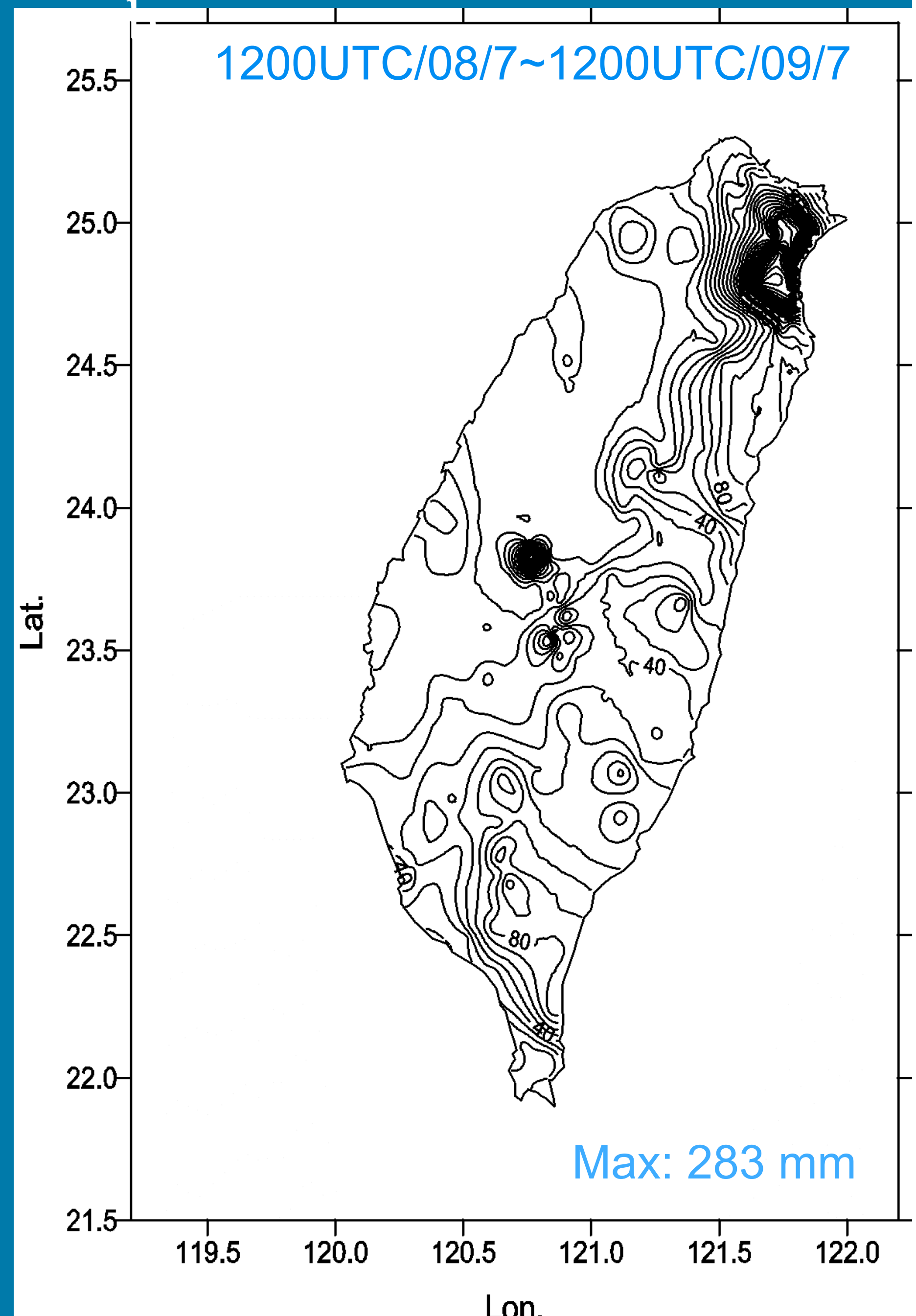


➢ **Some rainfall statistics is closer to the observed, with GPSrf assimilated**

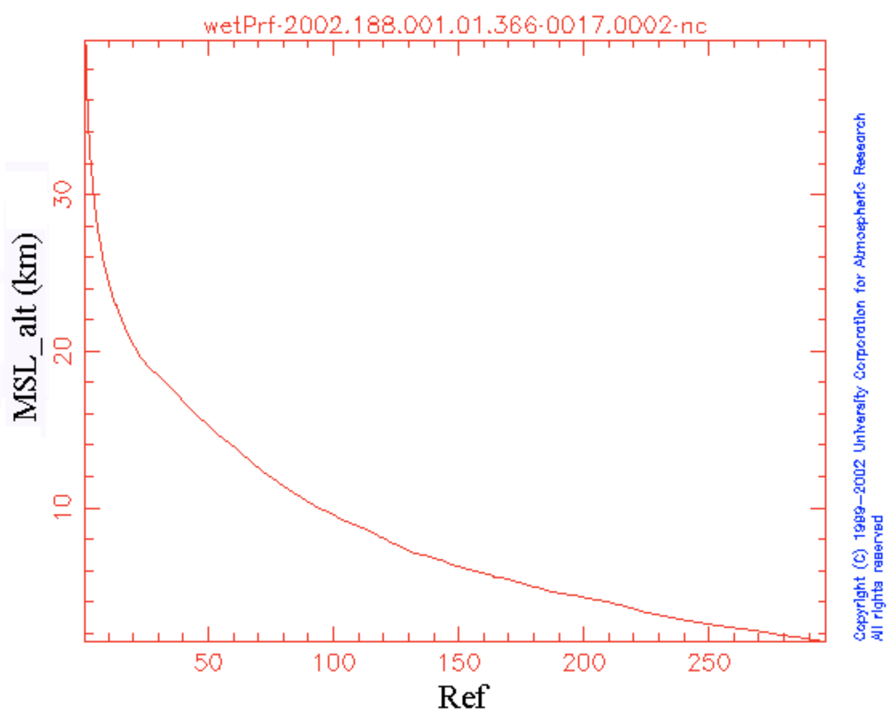


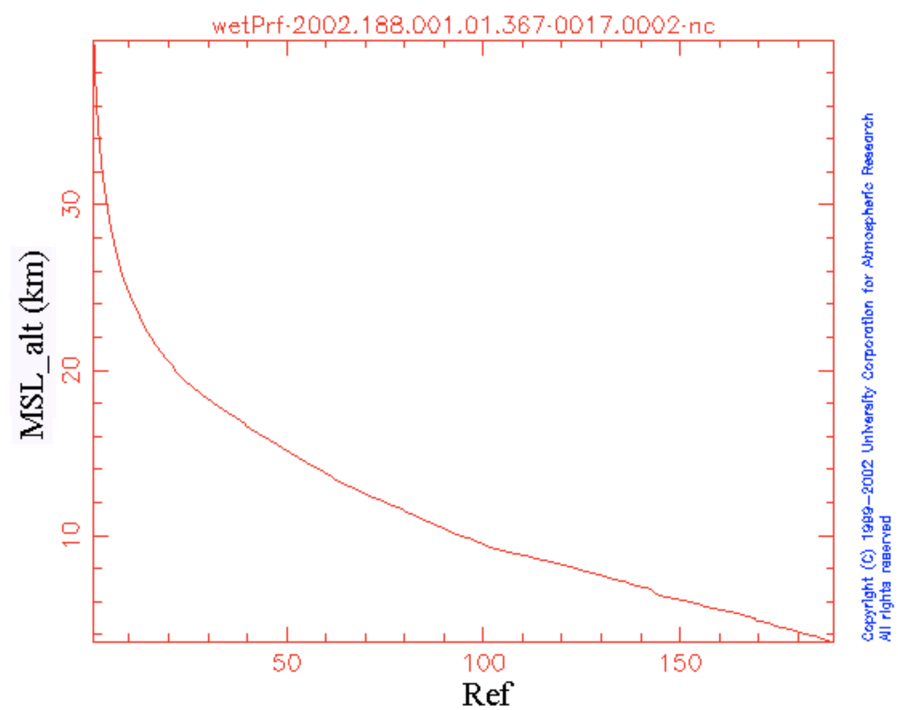
- Nakri headed for Taiwan from southwest, and was categorized as a tropical storm (not a typhoon yet).


1200UTC/07/7~1200UTC/08/7
Max: 154 mm
Lat.
Lon.
25.5
25.0
24.5
24.0
23.5
23.0
22.5
22.0
21.5
119.5
120.0
120.5
121.0
121.5
122.0


1200UTC/08/7~1200UTC/09/7
Max: 283 mm
Lat.
Lon.
25.5
25.0
24.5
24.0
23.5
23.0
22.5
22.0
21.5
119.5
120.0
120.5
121.0
121.5
122.0

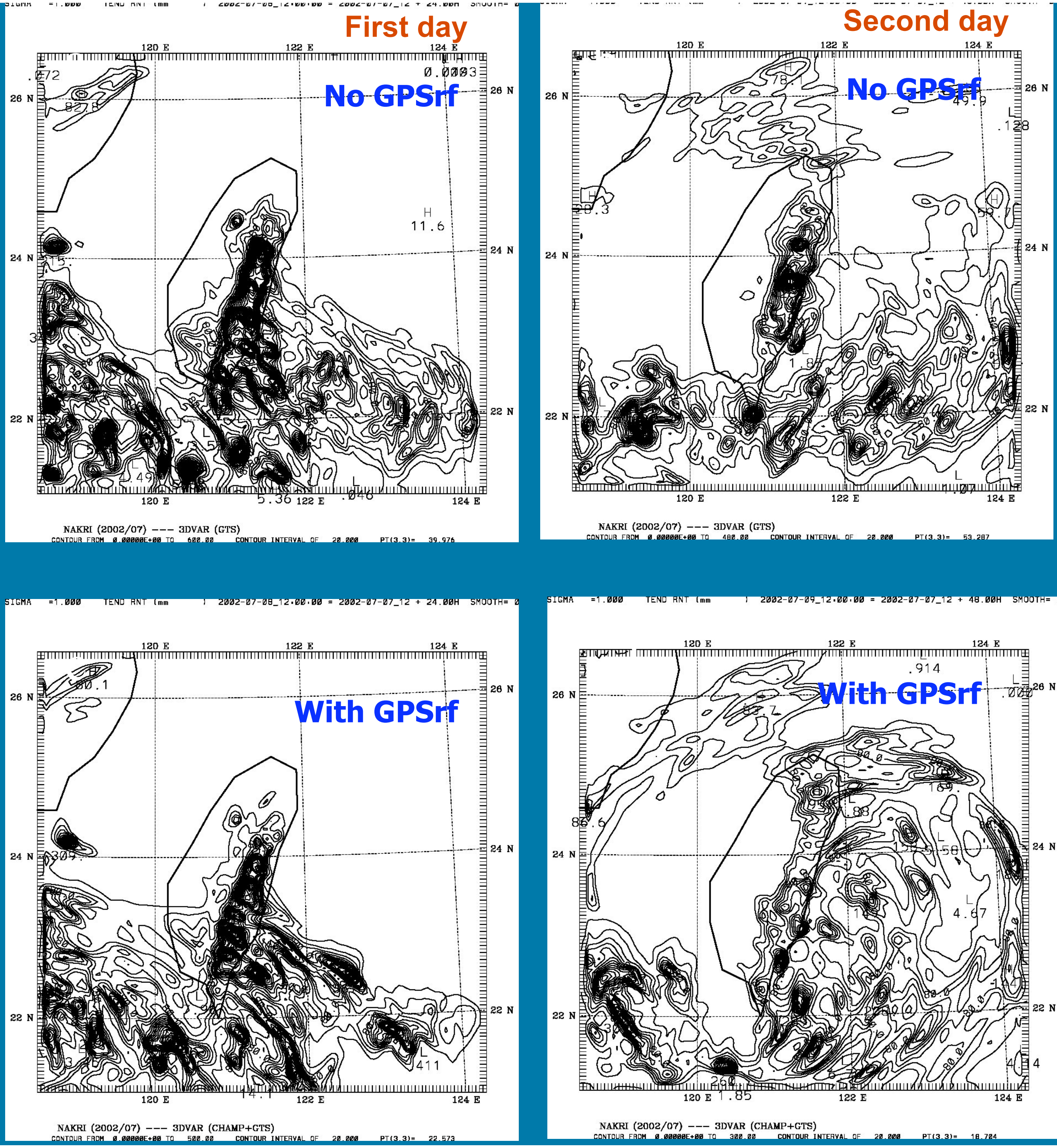
Domain-1 (45-km grid)





Domain-1 (45-km)

Wetprf.2002.188.001.01.366.0017.0002.nc	11:29	22.289	145.435
Wetprf.2002.188.001.01.367.0017.0002.nc	11:32	34.416	142.594
Wetprf.2002.188.001.01.412.0017.0002.nc	12:56	5.834	128.987
Wetprf.2002.188.001.01.413.0017.0002.nc	12:59	16.294	108.563
Wetprf.2002.188.001.01.417.0017.0002.nc	13:01	22.726	123.296



24-h accumulated rainfall (mm) for the Nakri case.

Threat Score (TS)

$$TS = \frac{A}{F + O - A}$$

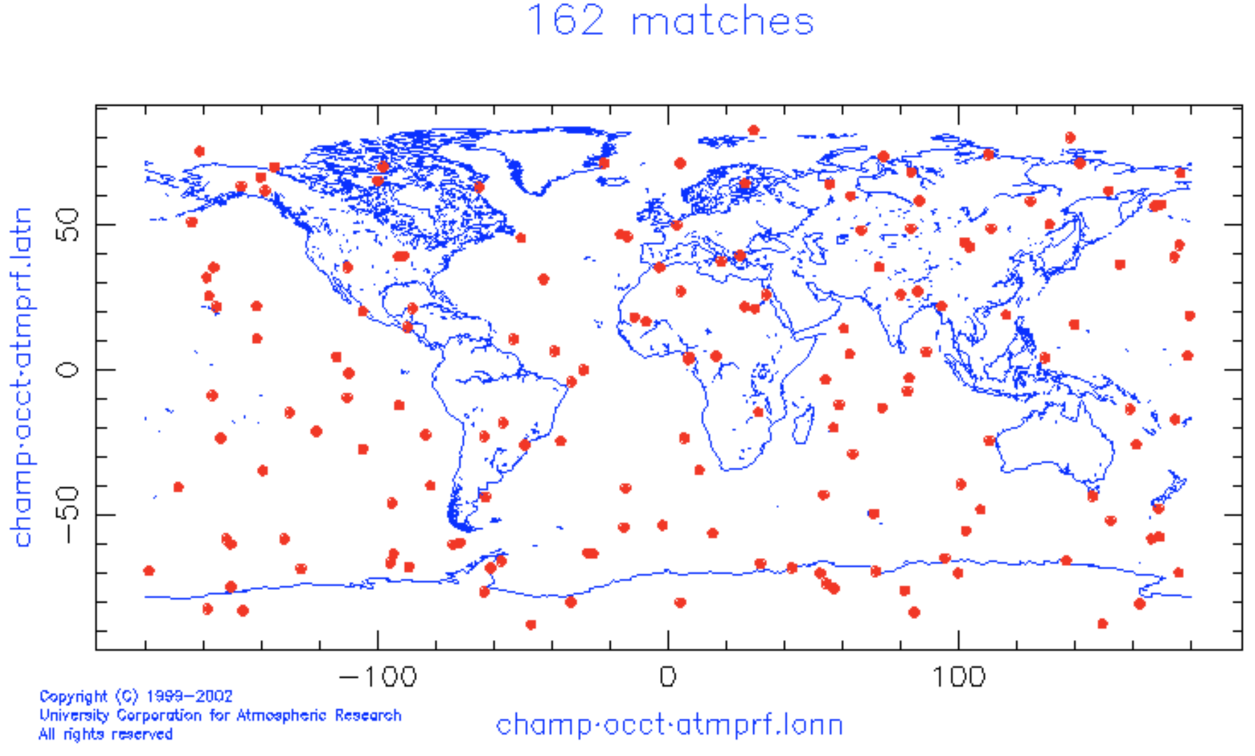
- *A:* the number of the grids on which both forecast and observation exceed the threshold,
- *F:* the number of the grids on which forecast exceeds the threshold, and
- *O:* the number of the grids on which observation exceeds the threshold.

> 1,500 verification grid points on the island.

Threat Scores

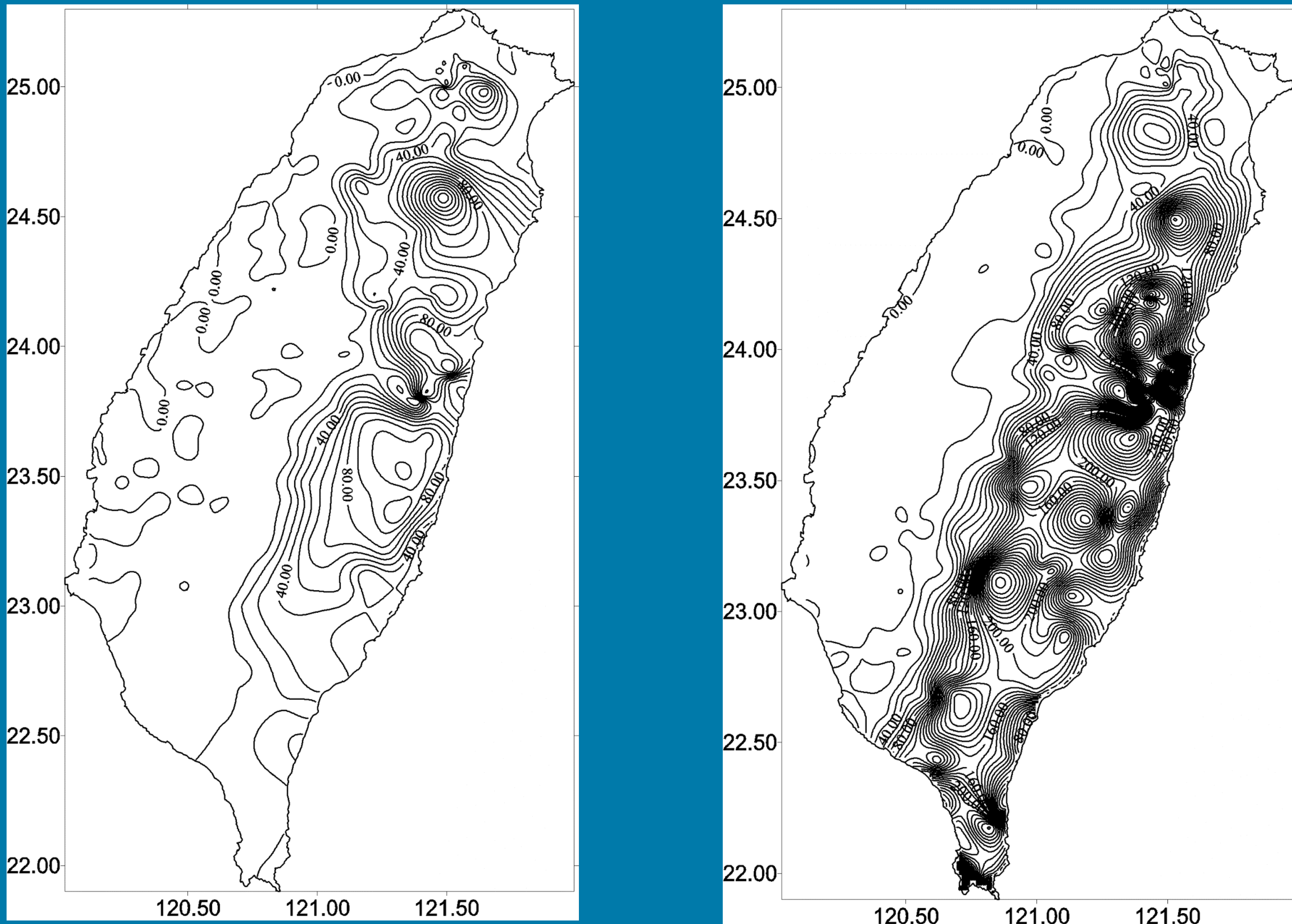
Cases / Thresholds	Nari *GTS*	Nari *GPSrf*	Nari *GTS*	Nari *GPSrf*	Nakri *GTS*	Nakri *GPSrf*	Nakri *GTS*	Nakri *GPSrf*
	0-24 h	0-24 h	24-48 h	24-48 h	0-24 h	0-24 h	24-48 h	24-48 h
0.25 mm	0.545	0.540	0.539	0.536	0.504	0.480	0.505	0.475
0.5 mm	0.544	0.539	0.538	0.535	0.482	0.464	0.498	0.448
1 mm	0.544	0.542	0.532	0.533	0.411	0.425	0.486	0.411
2 mm	0.530	0.524	0.527	0.531	0.376	0.363	0.463	0.378
5 mm	0.489	0.484	0.530	0.528	0.273	0.244	0.321	0.320
10 mm	0.489	0.492	0.527	0.530	0.182	0.174	0.277	0.278
15 mm	0.503	0.496	0.526	0.538	0.149	0.140	0.248	0.258
25 mm	0.524	0.496	0.543	0.531	0.126	0.127	0.233	0.235
50 mm	0.497	0.485	0.462	0.504	0.086	0.088	0.113	0.166
100 mm	0.473	0.444	0.277	0.393	0.009	0.000	0.000	0.129
RMSE (mm)	69.74	71.43	97.84	93.98	90.28	66.55	50.85	37.06

- **TS is generally higher for the run with assimilated QuikSCAT data.**



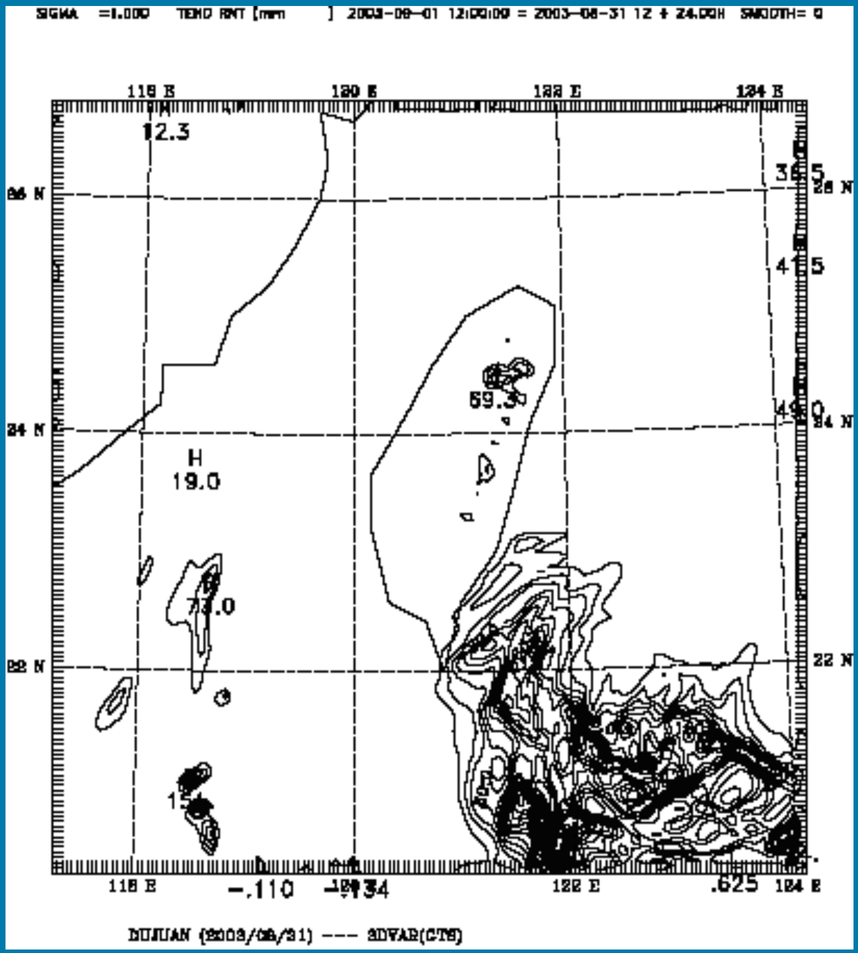
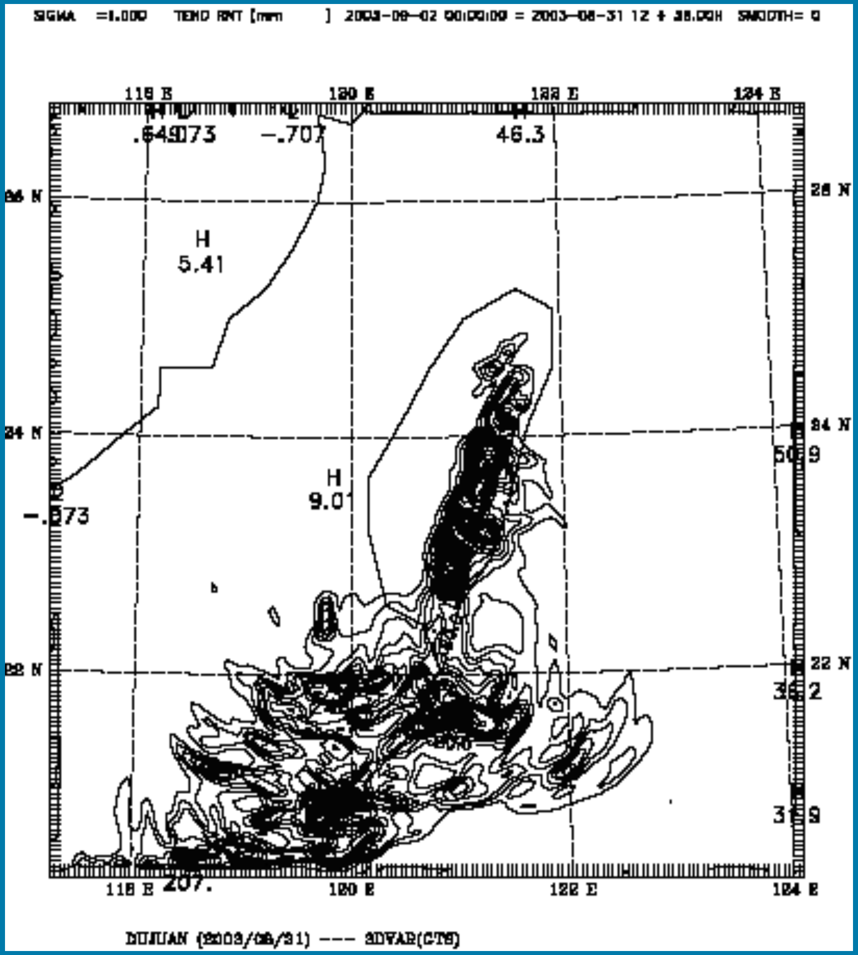
Satellite	Time	Location (Lat, Lon)
CHAMP	09:00	(4.24，129.91)
CHAMP	10:29	(10.47，102.36)
CHAMP	10:34	(-2.40，133.31)
CHAMP	11:54	(49.05，83.74)
CHAMP	11:57	(42.39，104.01)
CHAMP	13:32	(27.04，86.15)

Dujuan's simulation, initial time (1200UTC 31 August 2003) ± 3 hr



Observed rainfall for (a) 00-1200UTC 1 September 2003 (max: 166.806 mm), (b) 12-2400UTC 1 September 2003 (max: 657.744 mm).

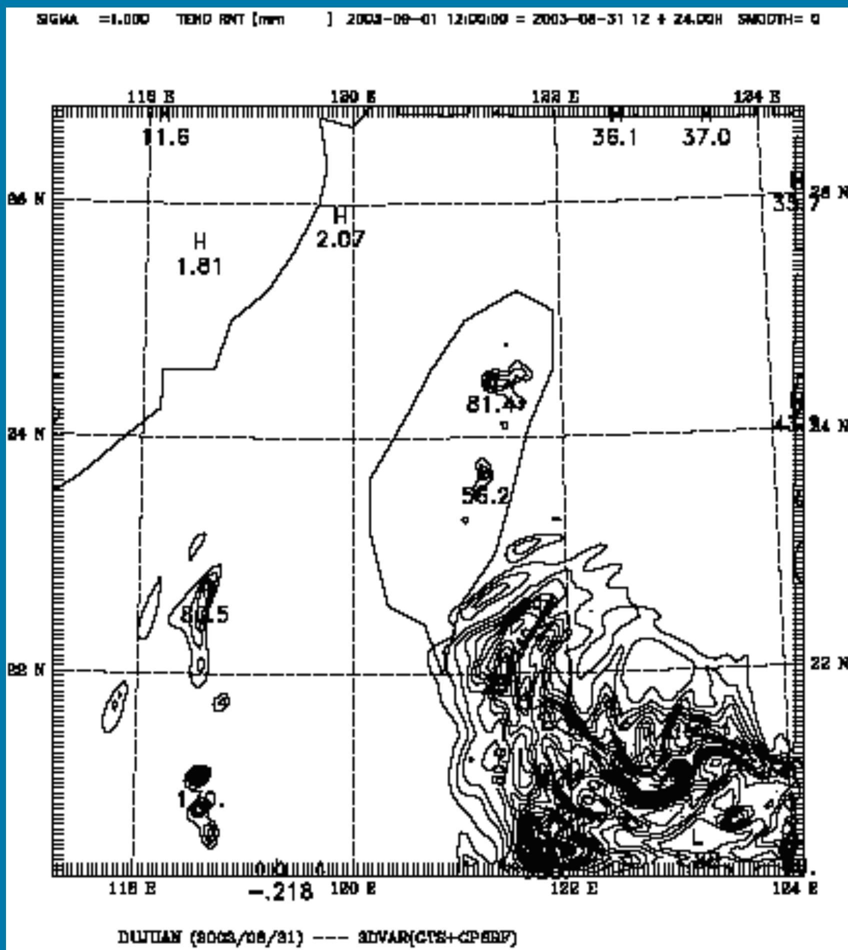
GTS only

09/01/00-12UTC	09/01/12-24UTC
69.3 mm	369 mm

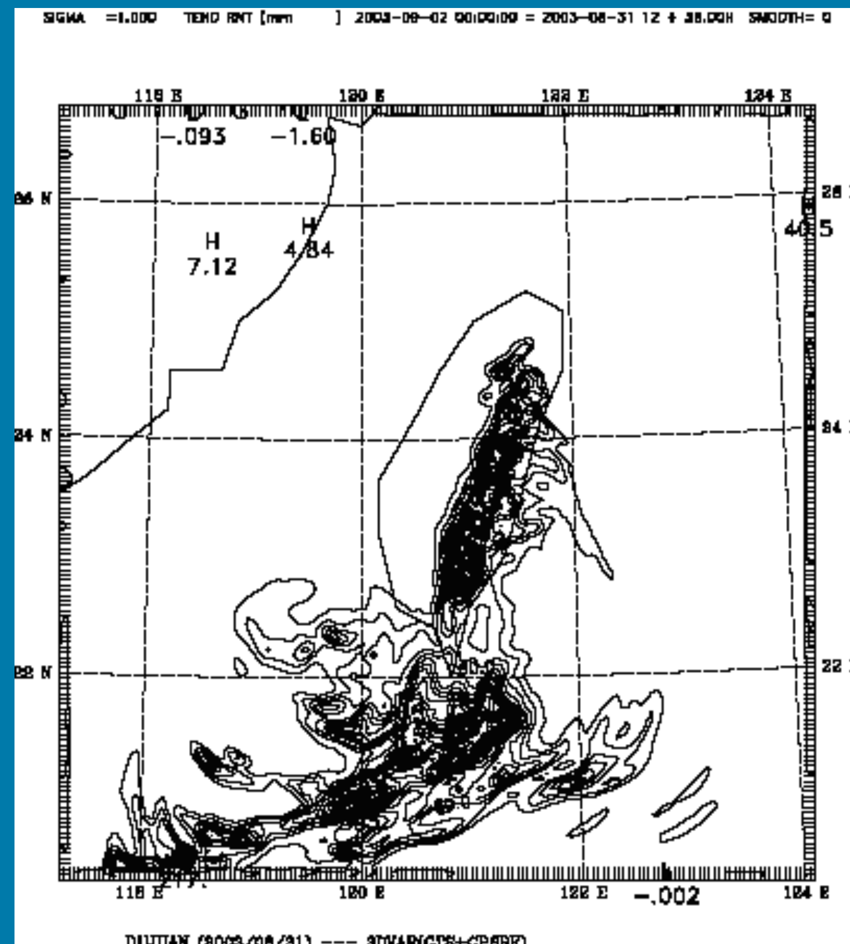
BOTH (GTS + GPSrf)

09/01/00-12UTC



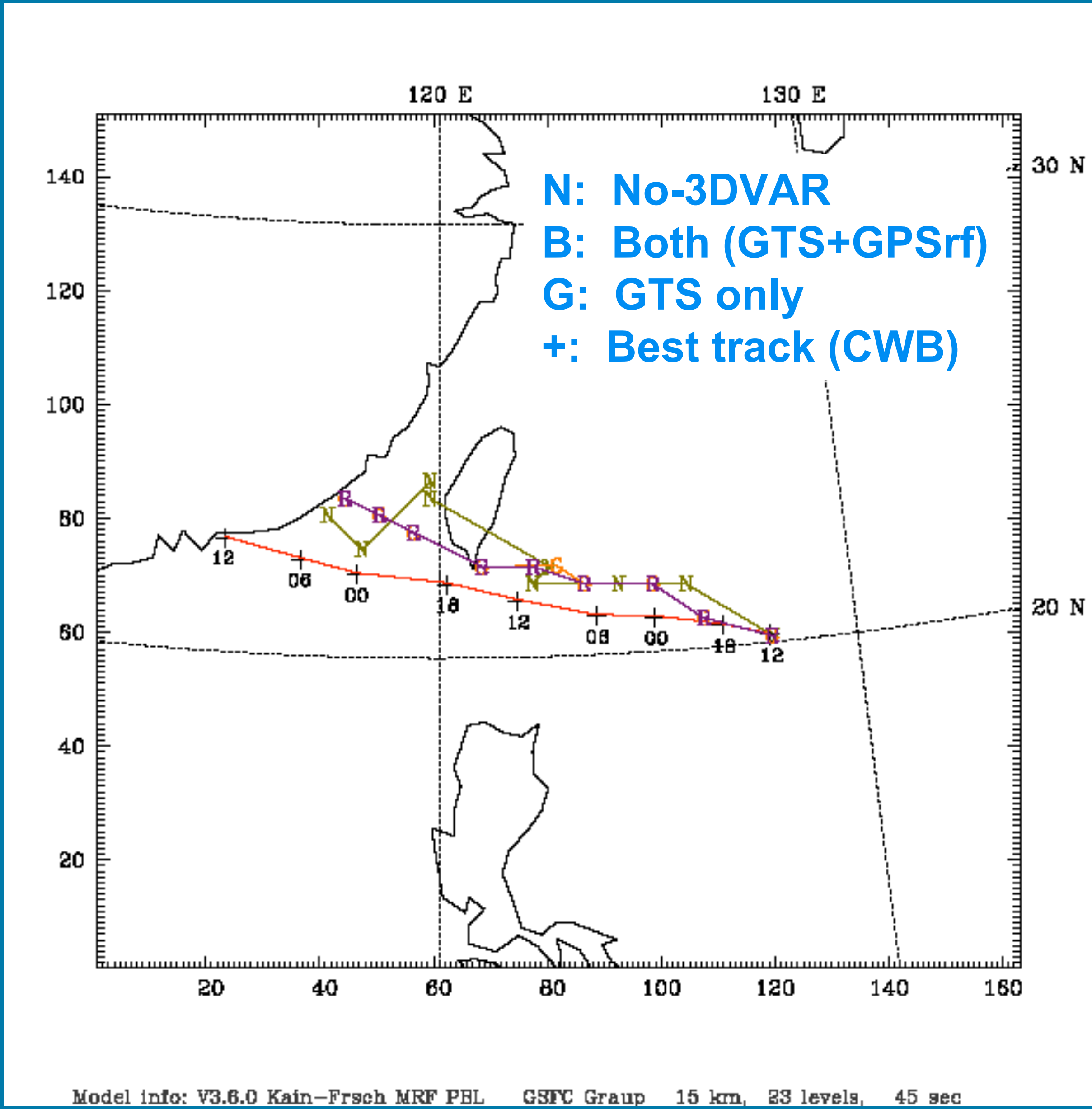
81.4 mm

09/01/12-24UTC



387 mm

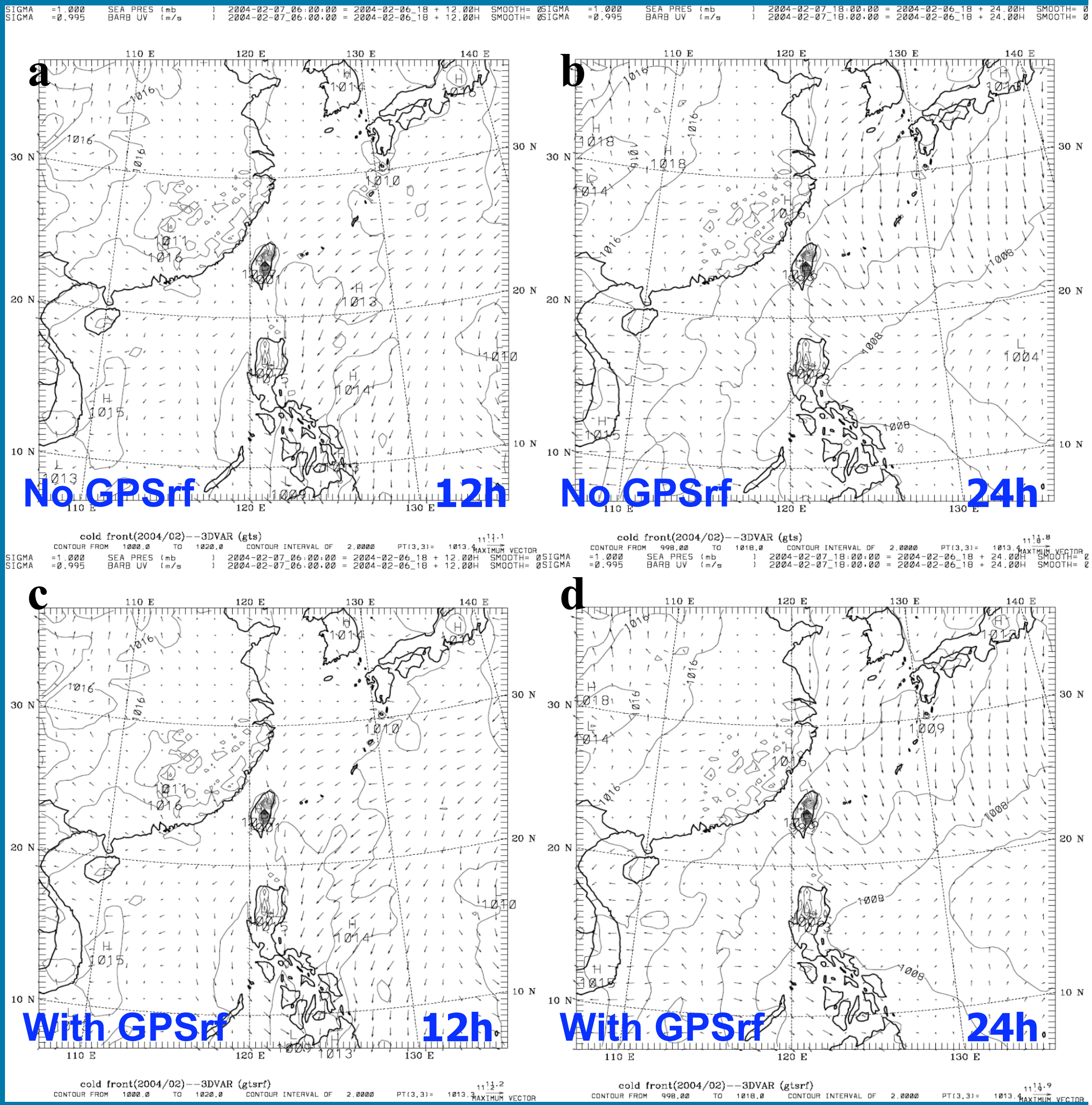
Dujuan Simulation



2004/02 Cold front

Initial time:2004/2/6/1800UTC

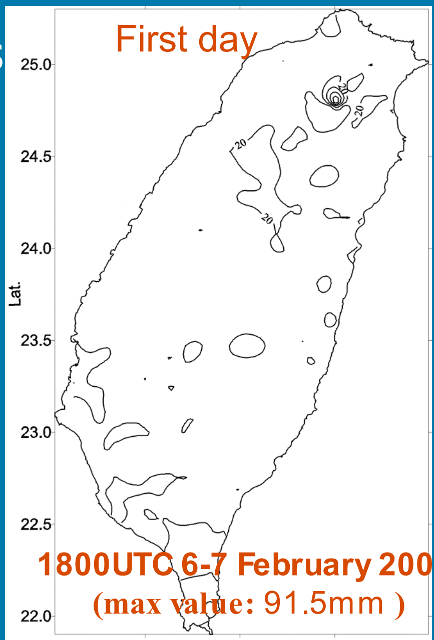
MM5 simulated near-surface pressure (mb) and wind (ms^{-1}) at 12h, 24h.

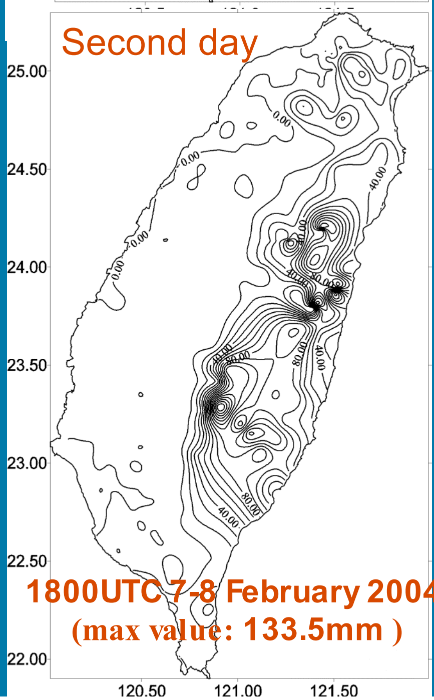


2004/02 Cold front

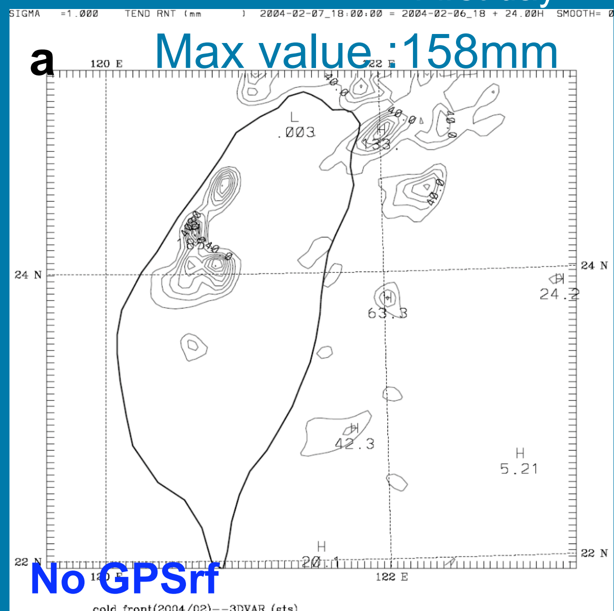
MM5 simulated 24-h accumulated rainfall (mm)

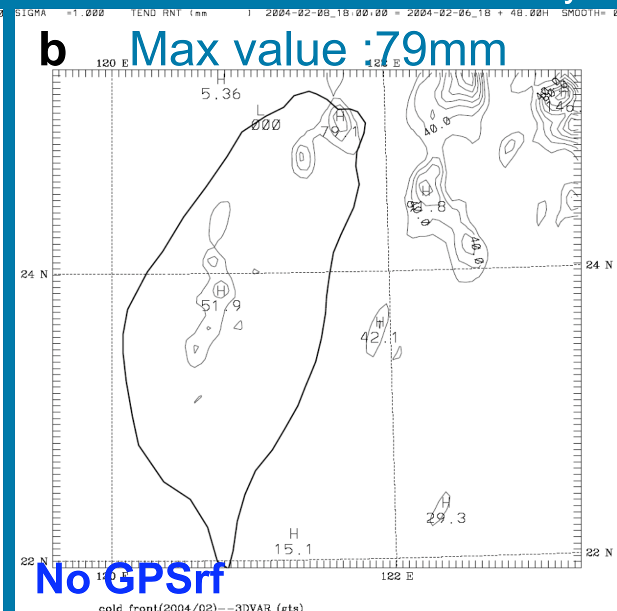
Obs

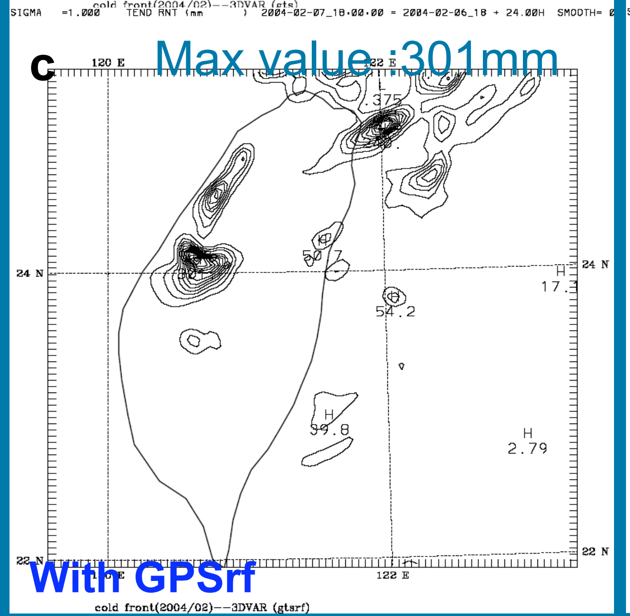


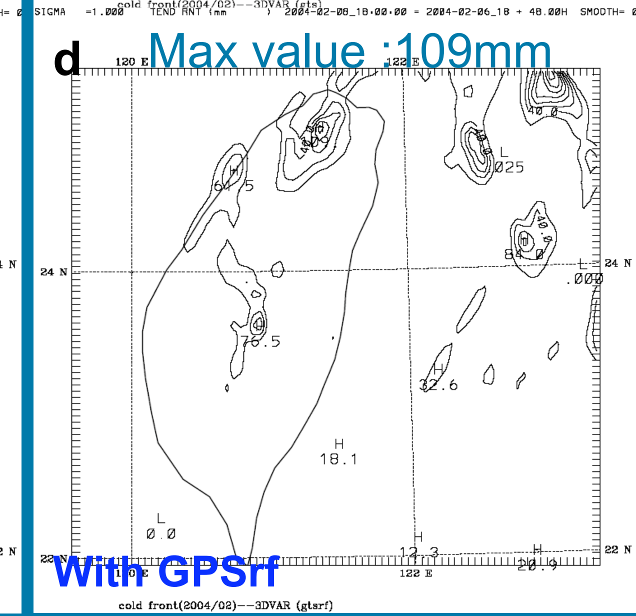


First day | Second day





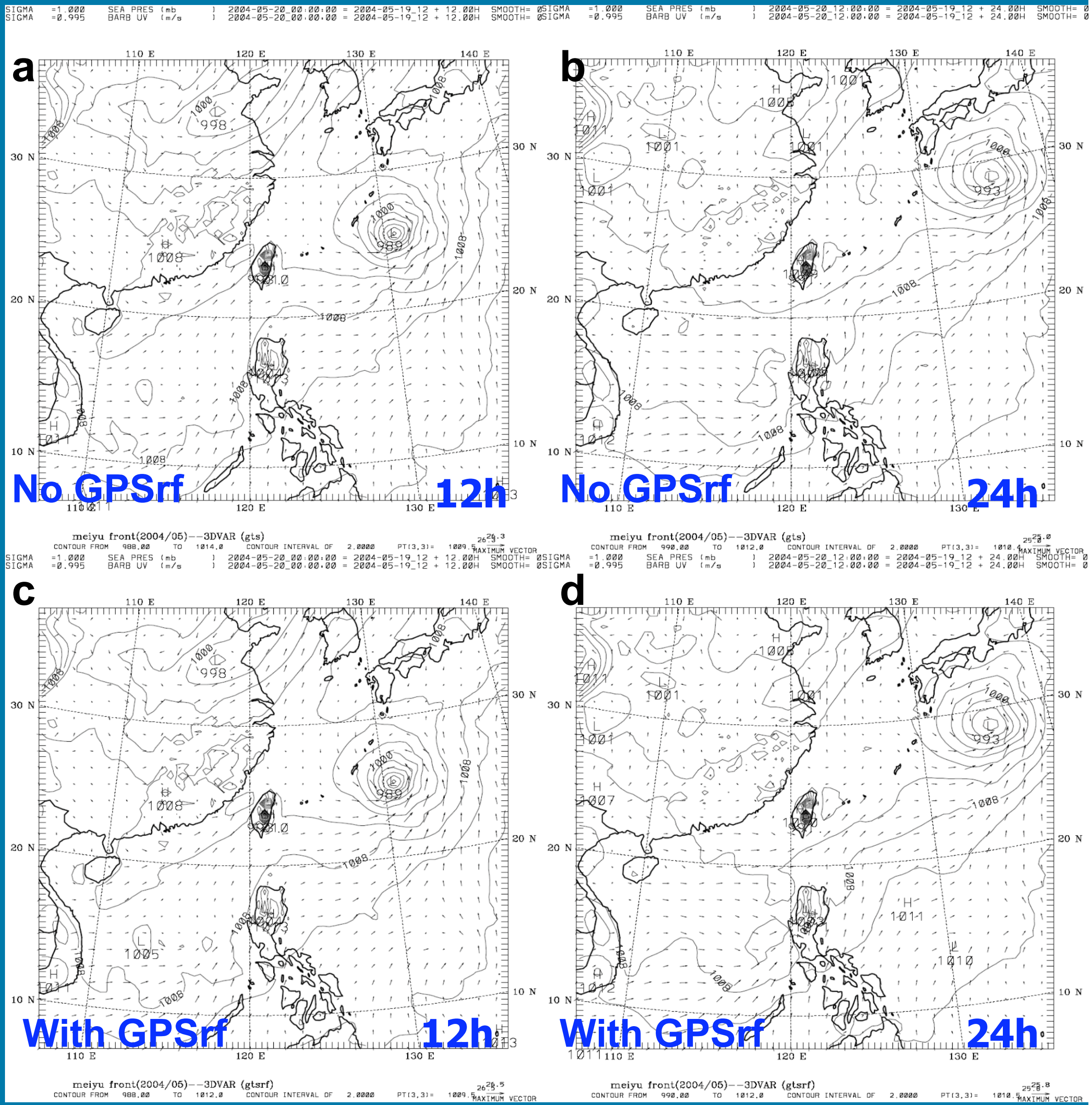




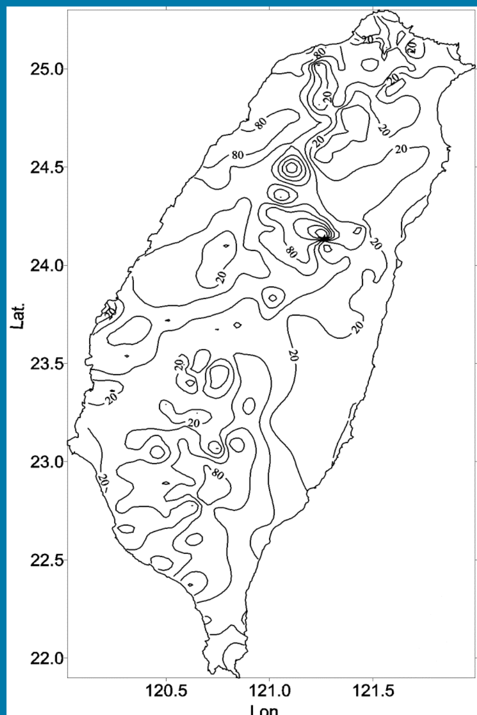
2004/05 Meiyu Front

MM5 simulated near-surface pressure (mb) and wind (ms^{-1}) at 12h, 24h.

Initial time:2004/5/19/1200UTC

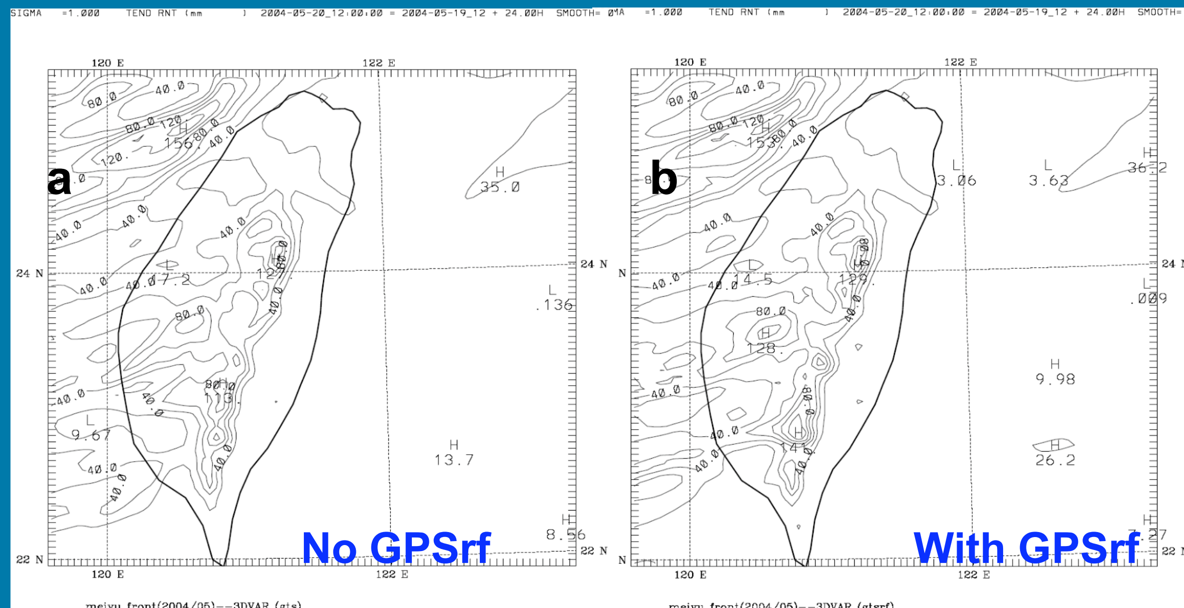


2004/05 Meiyu Front



1200UTC 19-20 May 2004
(max value: 162mm **)**

MM5 simulated 24-h accumulated rainfall (mm)

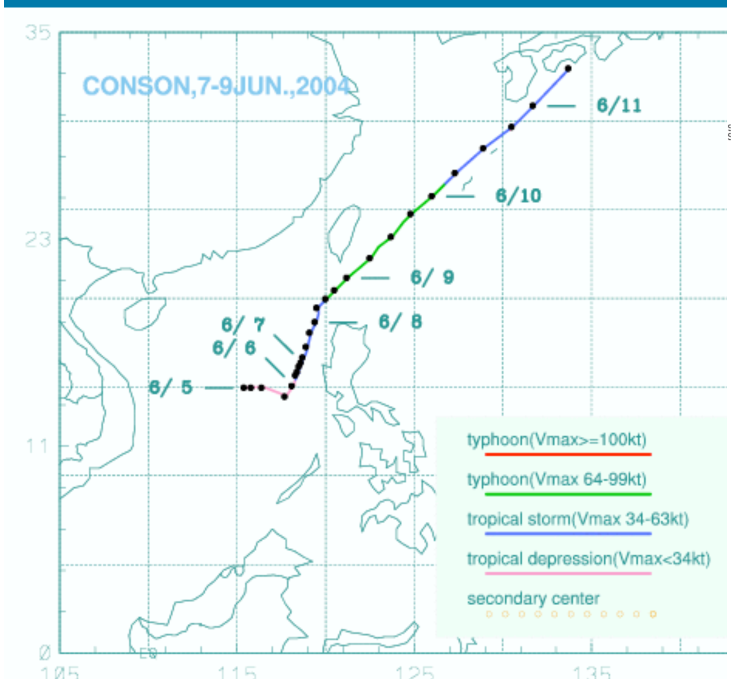


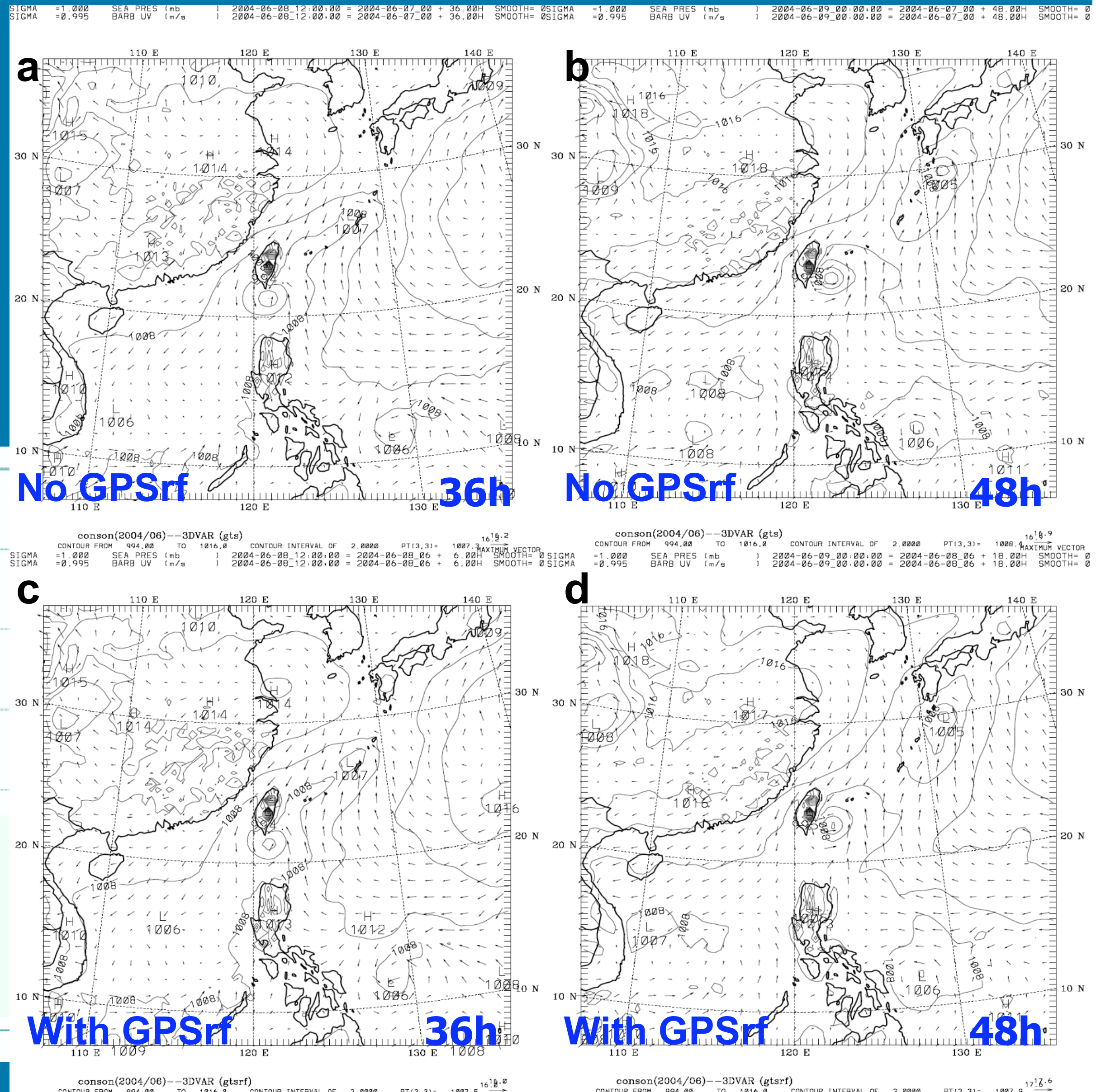
（a） **max value:127mm** (b） **max value:141mm** 。

2004/06 Conson Typhoon

Initial time:2004/6/7/0000UTC

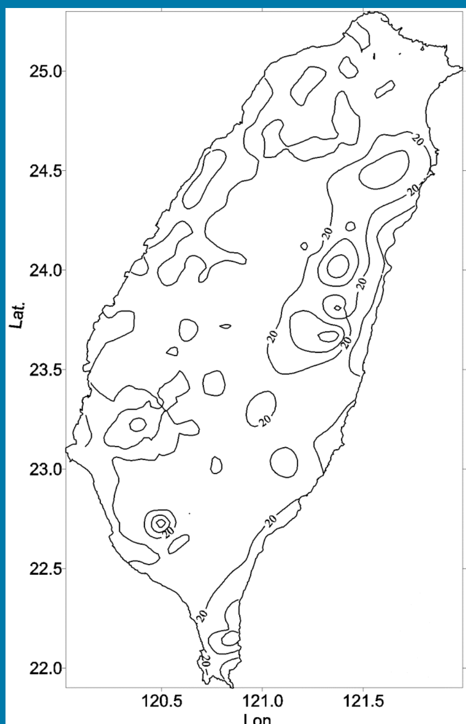
MM5 simulated near-surface pressure (mb) and wind (ms^{-1}) at 36h, 48h.



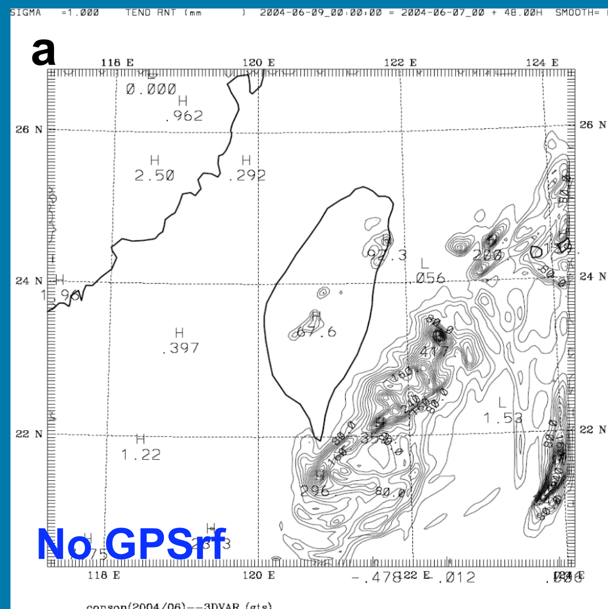


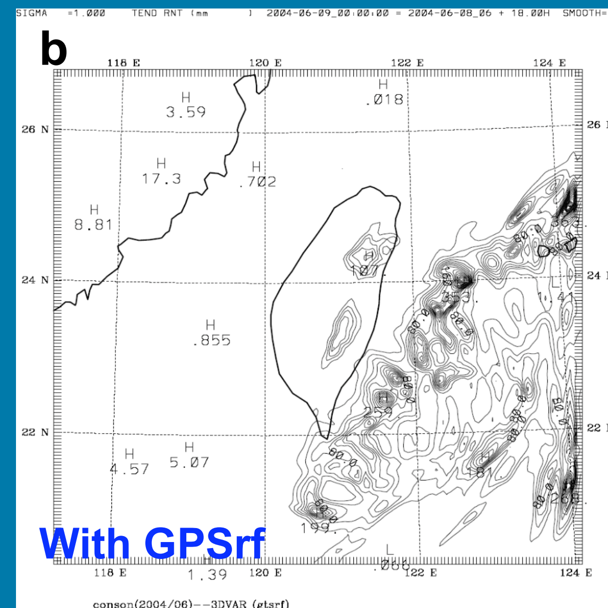
2004/06 Conson

MM5 simulated 18-h accumulated rainfall (mm)



0600-2400UTC 8 June 2004
(max value: 76.9mm)

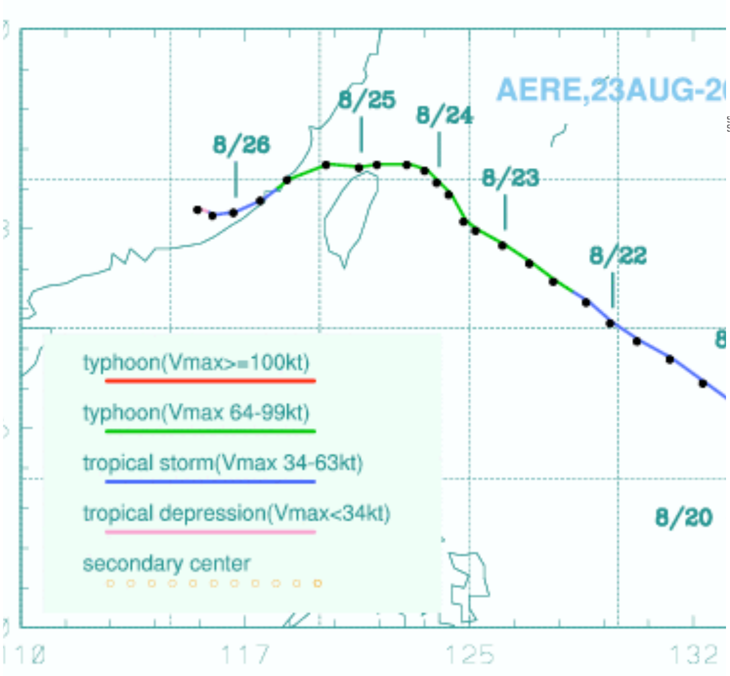




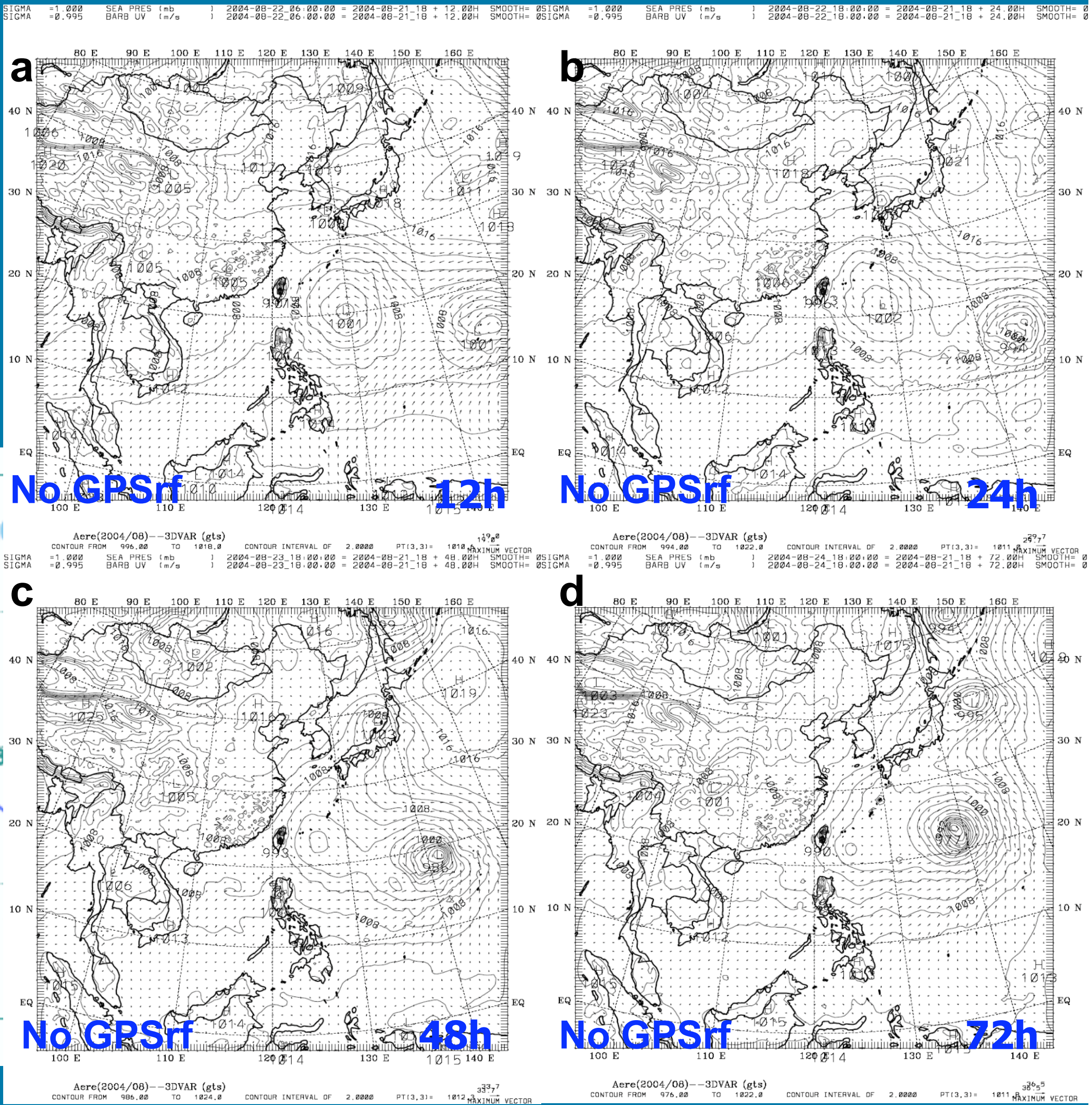
（a） **max value:92.3mm** (b） **max value:107mm** 。

2004/08 Aere Typhoon

MM5 simulated near-surface pressure (mb) and wind (ms^{-1}) at 12h,24h, 48h,72h.

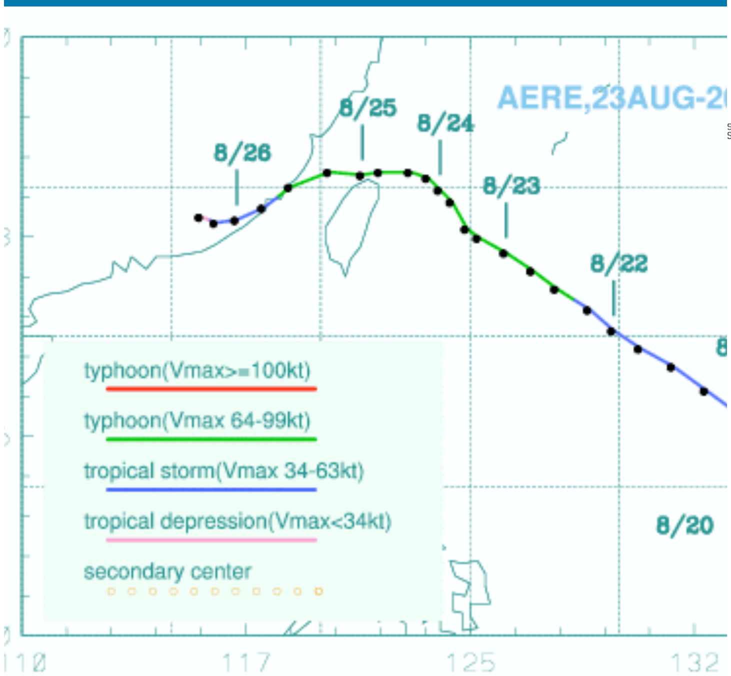


Initial time:2004/8/21/1800UTC

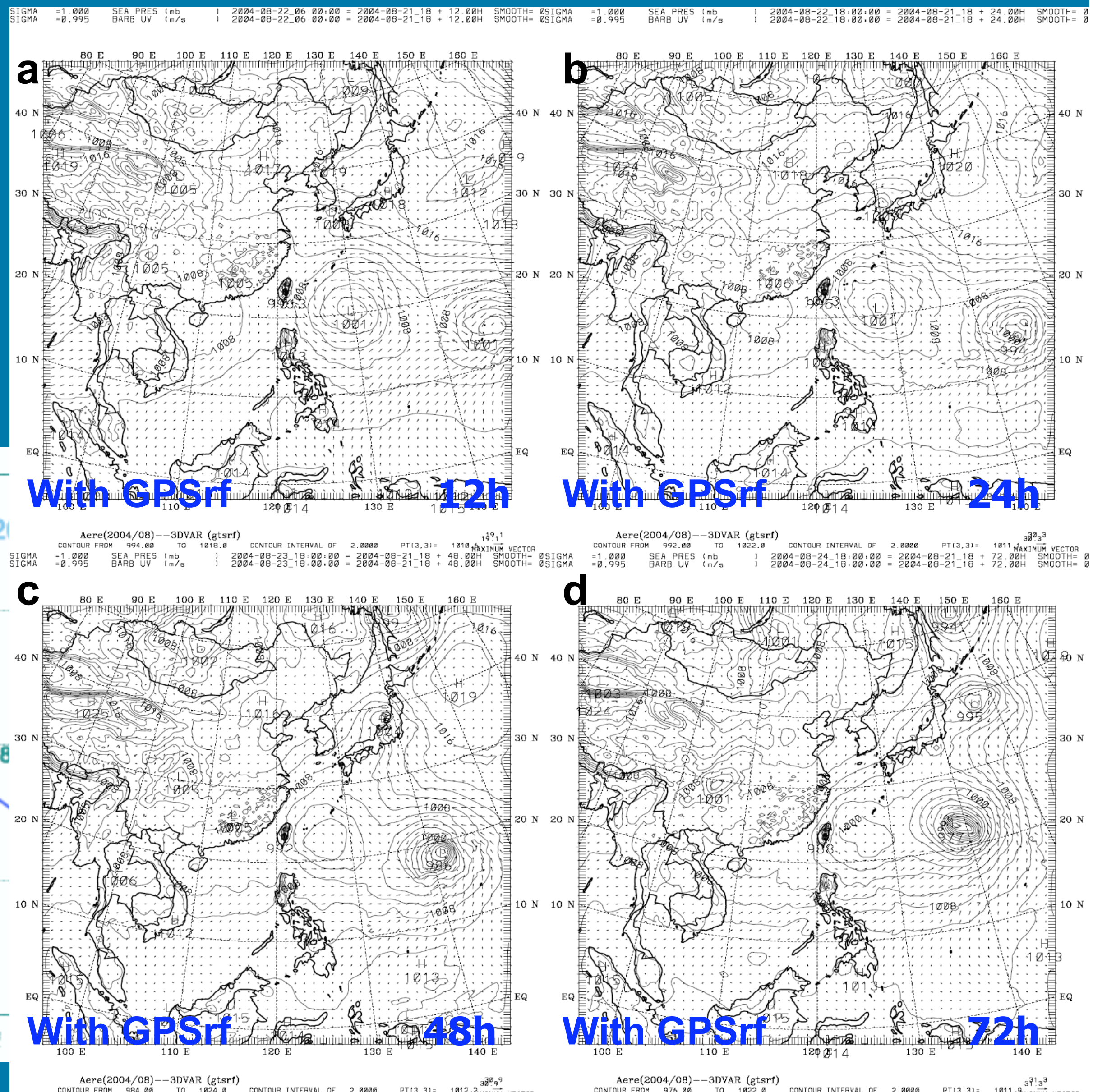


2004/08 Aere Typhoon

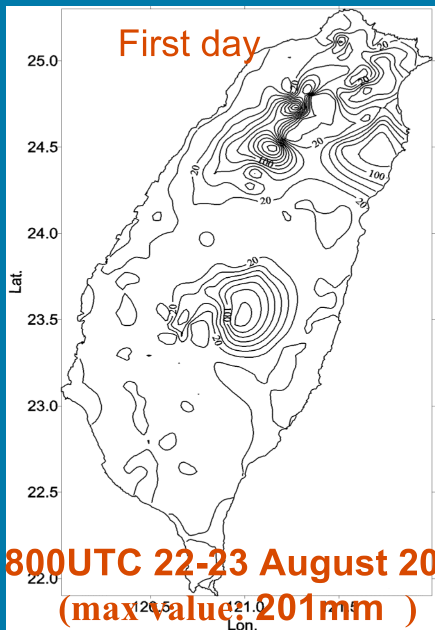
MM5 simulated near-surface pressure (mb) and wind (ms^{-1}) at 12h,24h, 48h,72h.



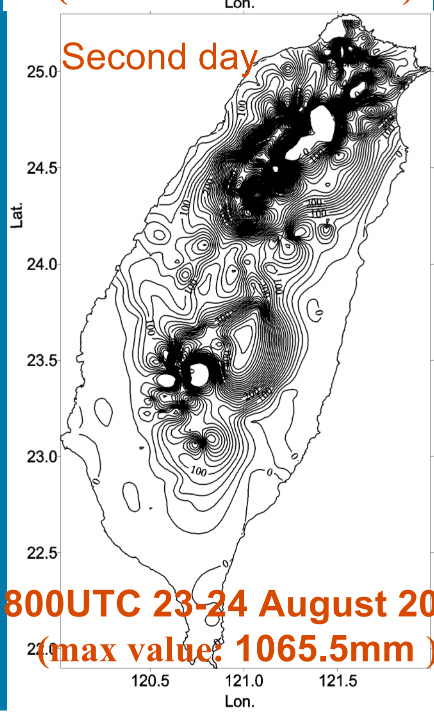
Initial time:2004/8/21/1800UTC



2004/08 Aere



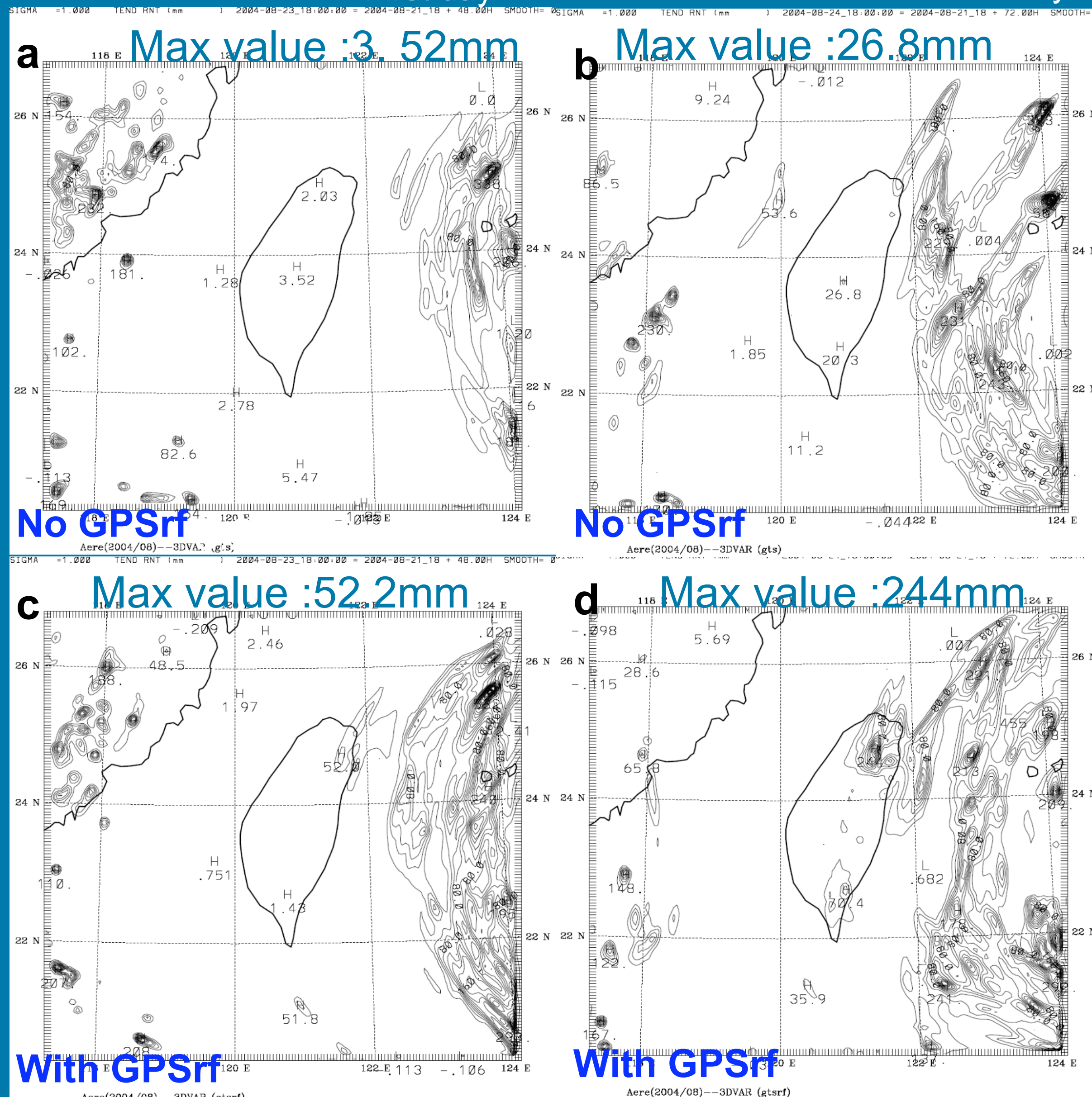
1800UTC 22-23 August 2004
(max value: 201mm)



1800UTC 23-24 August 2004
(max value: 1065.5mm)

MM5 simulated 24-h accumulated rainfall (mm)

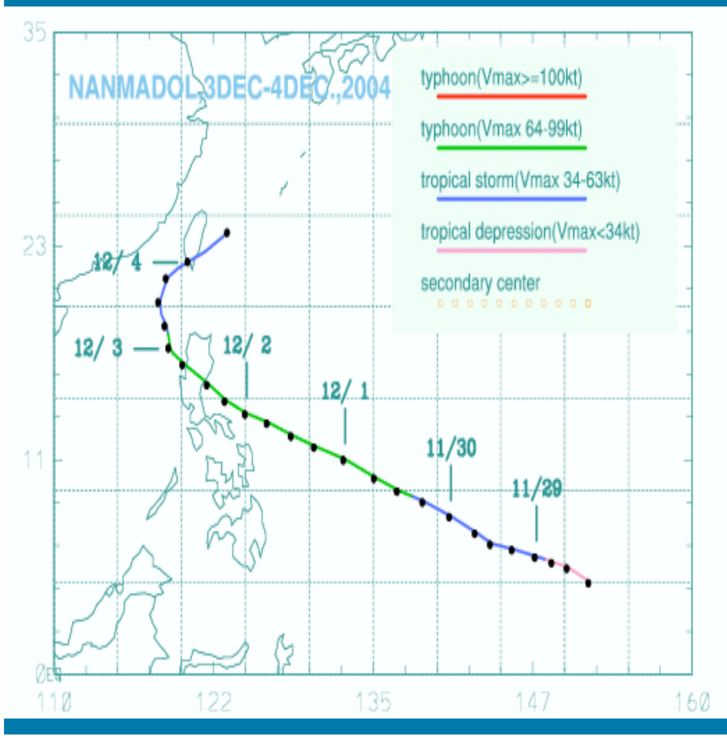
First day | Second day

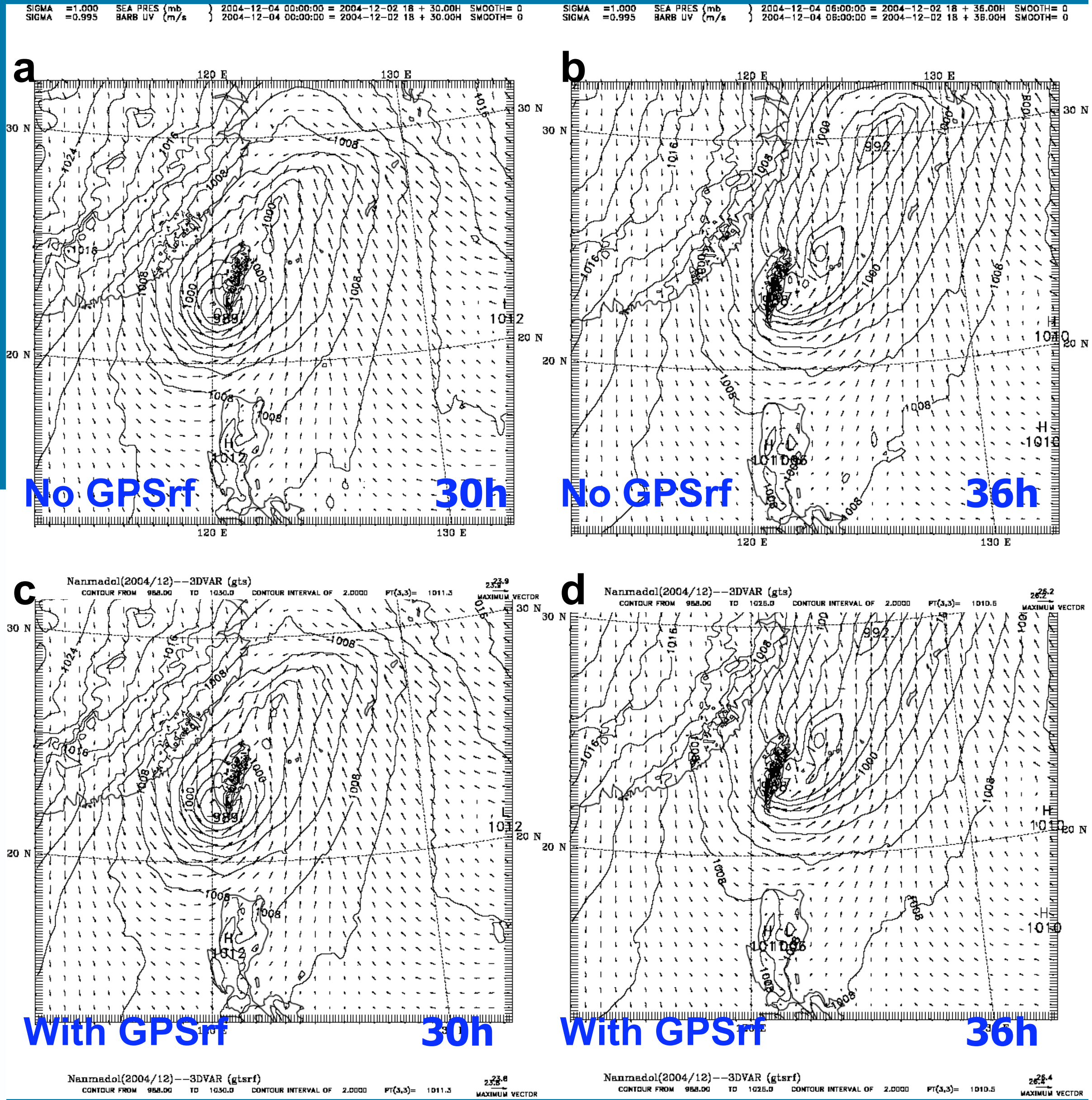


2004/12 Nanmadol Typhoon

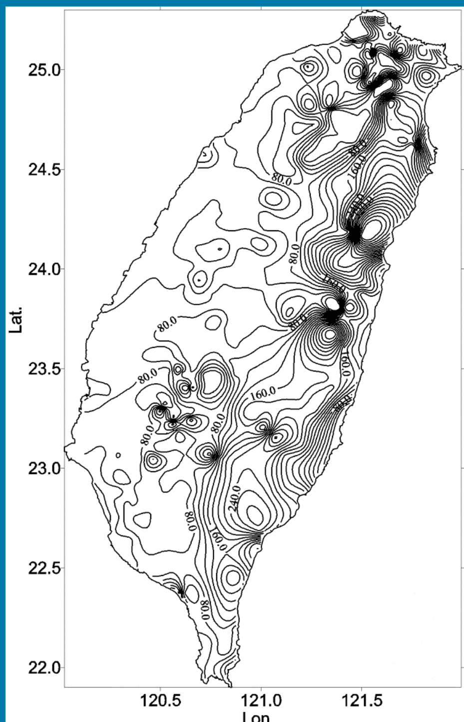
Initial time:2004/12/02/1800UTC

MM5 simulated near-surface pressure (mb) and wind (ms^{-1}) at 30h,36h,



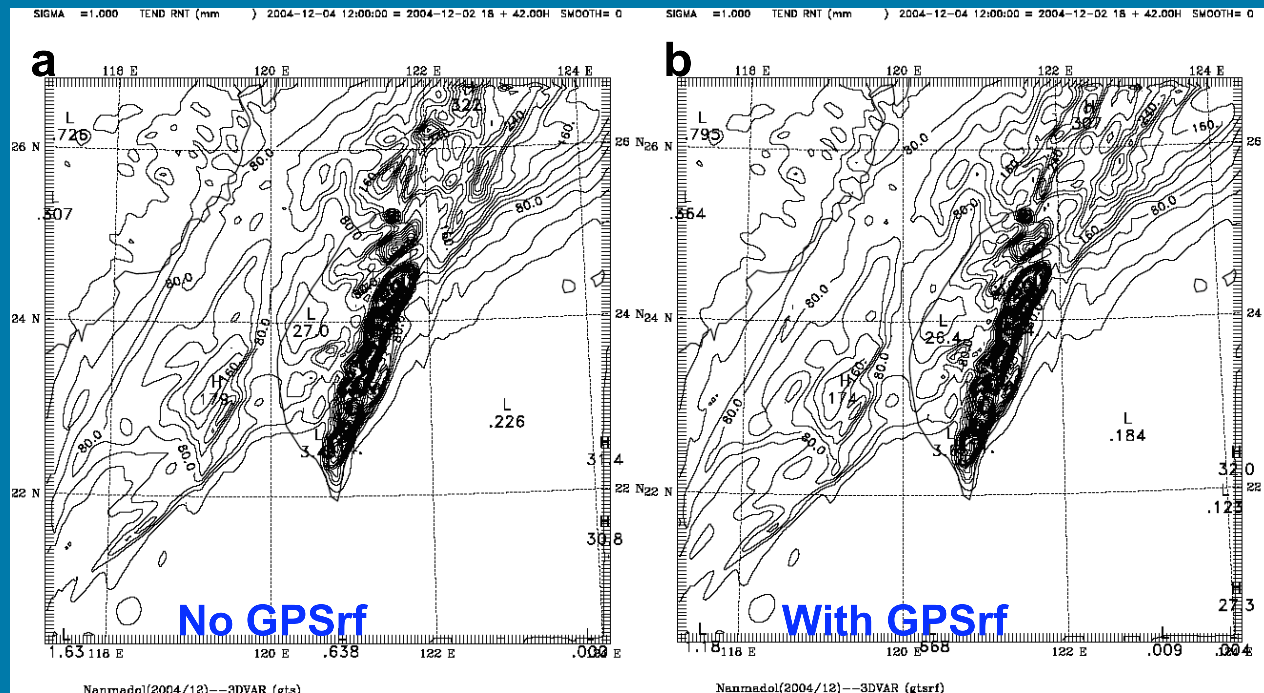


2004/12 Nanmadol

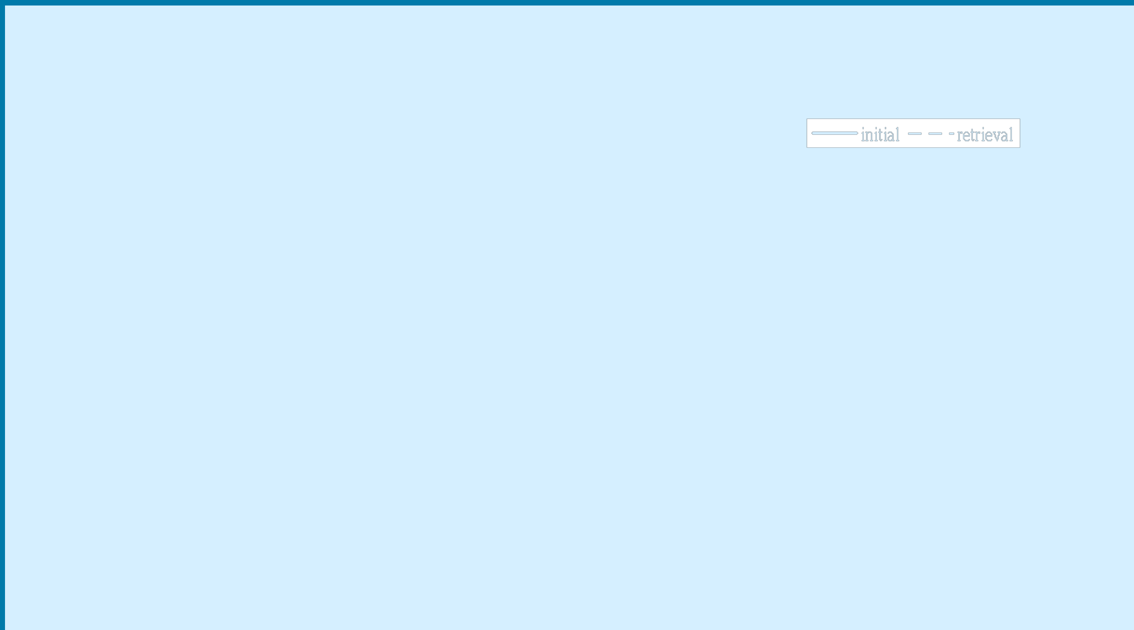


1200UTC 3-4 December 2004
(max value:528.9mm)

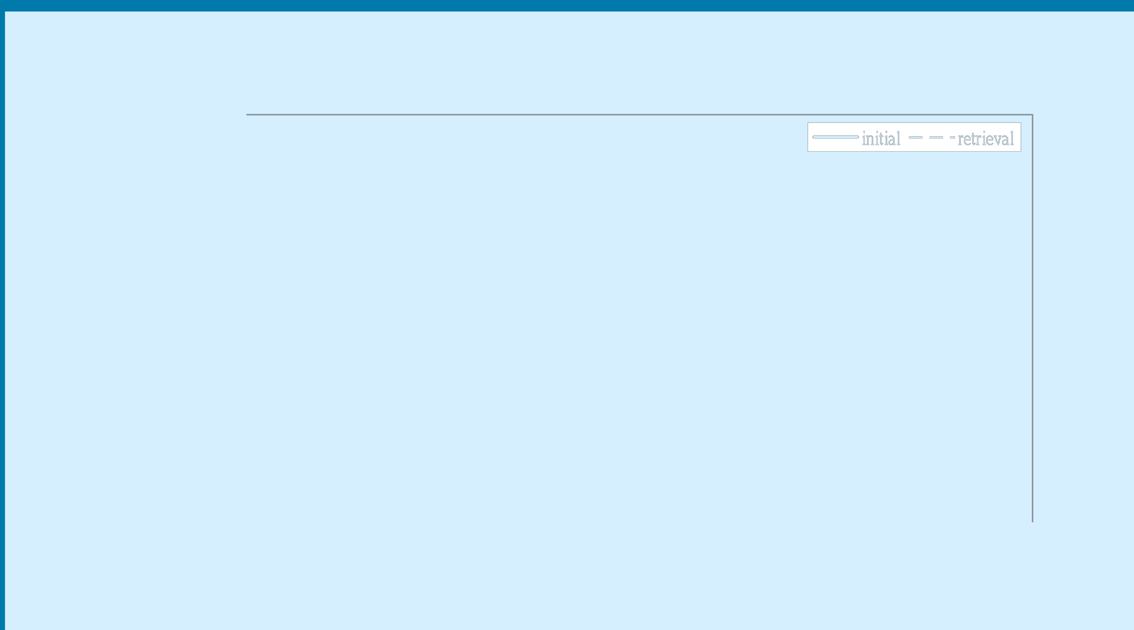
MM5 simulated 24-h accumulated rainfall (mm)



（a） **max value:561mm** (b） **max value:554mm** 。



→ About 5-10 % differences



The model local refractivity (solid line) and Abel-retrieved refractivity (dash line) obtained by ray-tracing near Taipei using the 12-h forecast results at (a) domain 1 (45-km) and (b) domain 2 (15-km) for the Nari case.

$$\frac{d^2\vec{x}}{d\tau^2} = n\vec{\nabla}n$$

$$(n = 1 + \nu)$$

$$S = \int \nu \, d\ell$$

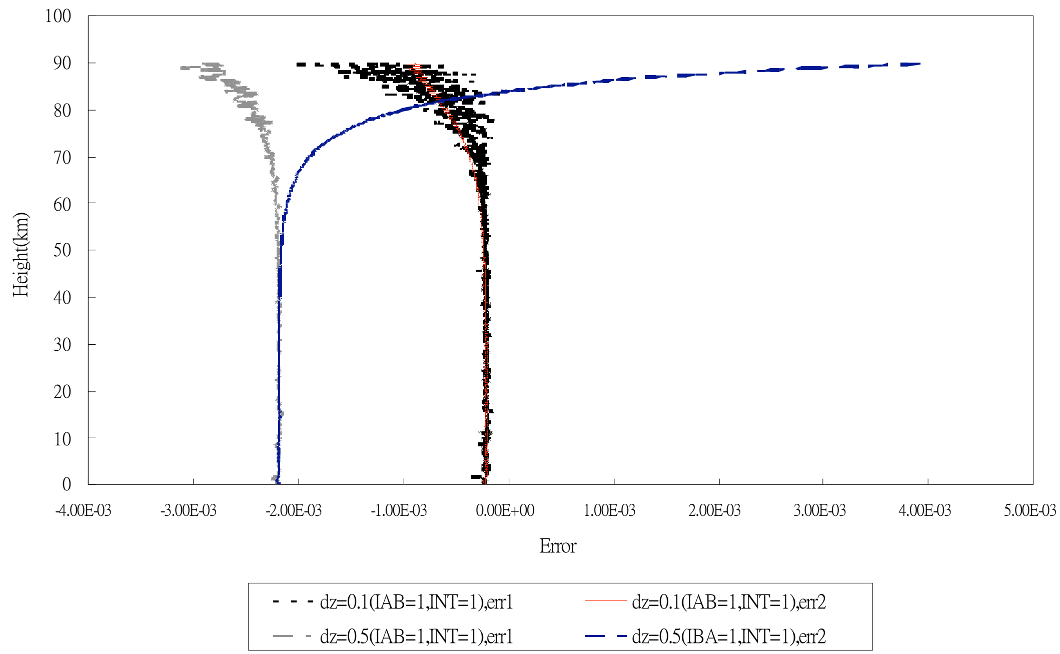
Sokolovskiy et al. (2004)
is an alternative method for excess phase.

Table. Average relative refractivity (N) error and relative excess phase (S) error below 90 km calculated by nonlocal straightline operator (NSO) for a profile of Abel refractivity.

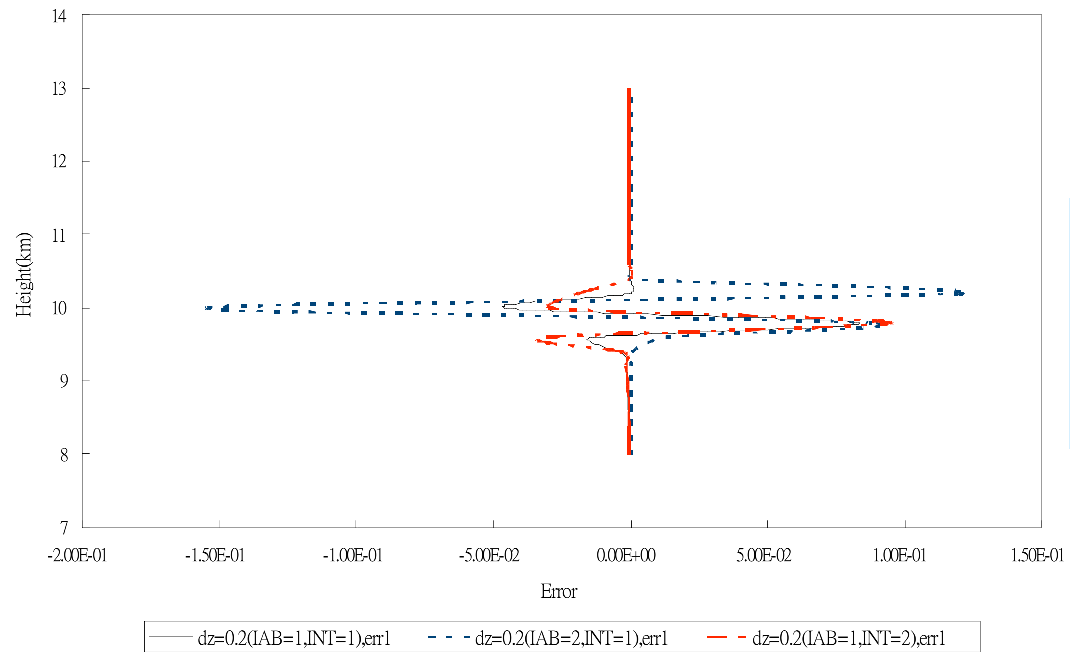
INT=1: Linear interpolation; INT=2: Cubic interpolation
IAB=1: Abel inversion scheme 1; IAB= 2: Abel inversion scheme 2

△z=0.1 km	IAB=1 (err1, err2)	IAB=2 (err1, err2)
INT=1	(3.117E-04, 6.371E-04)	(1.005E-04, 2.973E-04)
INT=2	(3.197E-04, 6.562E-04)	(9.826E-05, 2.939E-04)
△z=0.2 km	IAB=1 (err1, err2)	IAB=2 (err1, err2)
INT=1	(6.850E-04, 1.262E-03)	(1.500E-04, 3.360E-04)
INT=2	(7.171E-04, 1.329E-03)	(1.304E-04, 3.017E-04)
△z=0.5 km	IAB=1 (err1, err2)	IAB=2 (err1, err2)
INT=1	(2.268E-03, 4.257E-03)	(7.525E-04, 1.540E-03)
INT=2	(2.464E-03, 4.623E-03)	(5.579E-04, 1.152E-03)

err1= (N_mapping – N_Abel)/N_Abel from Abel inversion of S
err2= (S_mapping – S_Abel)/S_Abel from NSO for N_mapping



without a spike, (a) dz= 0.1 km (IAB=1, INI=1), err1, err2; (b) dz= 0.5 km (IAB=1, INI=1), err1, err2.



with a spike of N (=130) at z= 10 km, (a) dz= 0.2 km (IAB=1, INI=1), err1 (b) dz= 0.2 km (IAB=2, INI=1), err1, (c) dz= 0.2 km (IAB=1, INI=2), err1.

Comments on Nonlocal Refractivity Operator Assimilation

- Errors increase considerably near upper boundary, due to the less cancellation effects in a shorter path. Thus, local refractivity operator may still be recommended above the tropopause.

- The refractivity mapping normally has even larger errors compared to errors for excess phases, due to the application of Abel inversion in a finite domain with non-negligible local refractivity.
-
- The straightline forward operator is very fast and the assimilation should be computationally much more efficient than bending angle ray-tracing assimilation.

Comments on Ray-tracing Assimilation for Regional Modeling

- Convergence rate in cost-function minimization may be quite low, due to the nonlinearity of the ray path and the sensitivities to any tiny variations of the model state.

- The ray may still have considerable bending near the model lateral boundary.

- The ray-tracing assimilation is computationally much more expensive than local-refractivity and nonlocal excess phase assimilations.