Application of the Multi-scale Blending Scheme on the Continuous Cycling Radar Data Assimilation:

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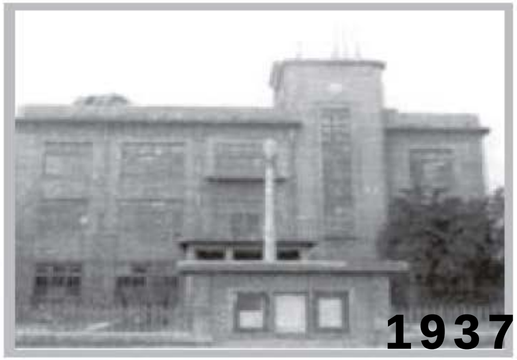
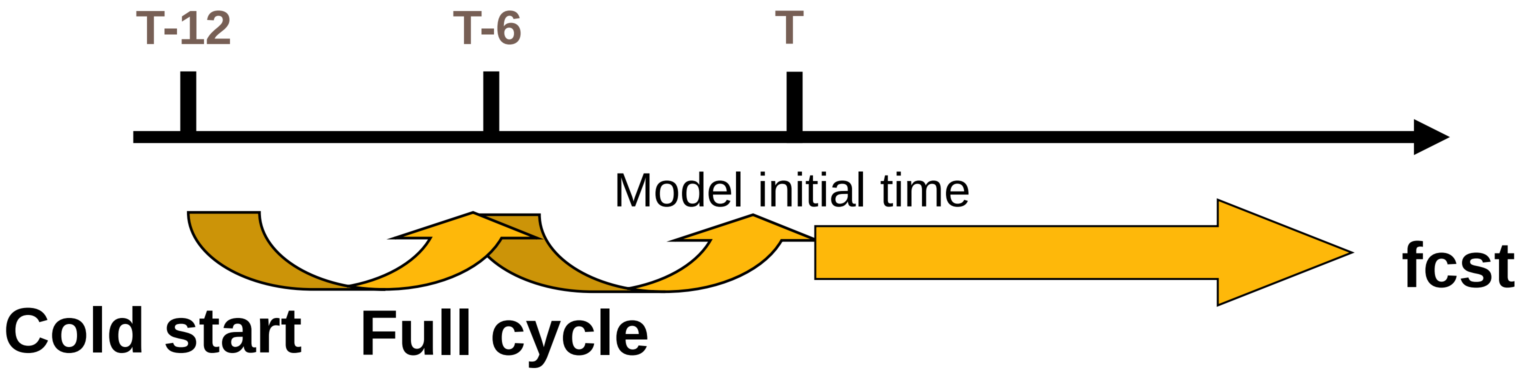


Data assimilation strategy is one of the critical issues to provide the reliable firstguess and the ROBUST model prediction

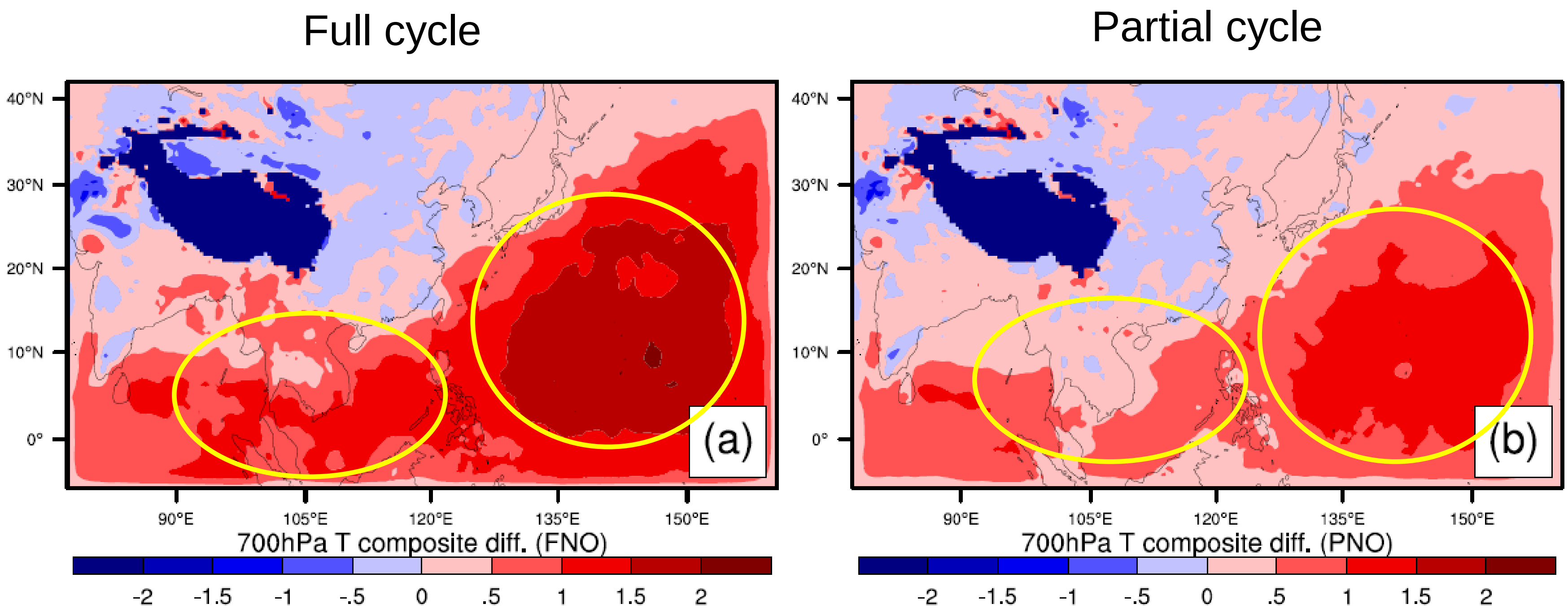
Especially in operational consideration

- Applying the partial cycle strategy
  - Cold start from NCEP GFS at the previous-12 hr, and cycling in every 6-hr interval



- Take the advantage from the GFS analysis to avoid the bias drift over the data void area.
- The 12-hr model forecast improve the spin-up problems from the cold-start initial condition.

Impact of the partial cycle

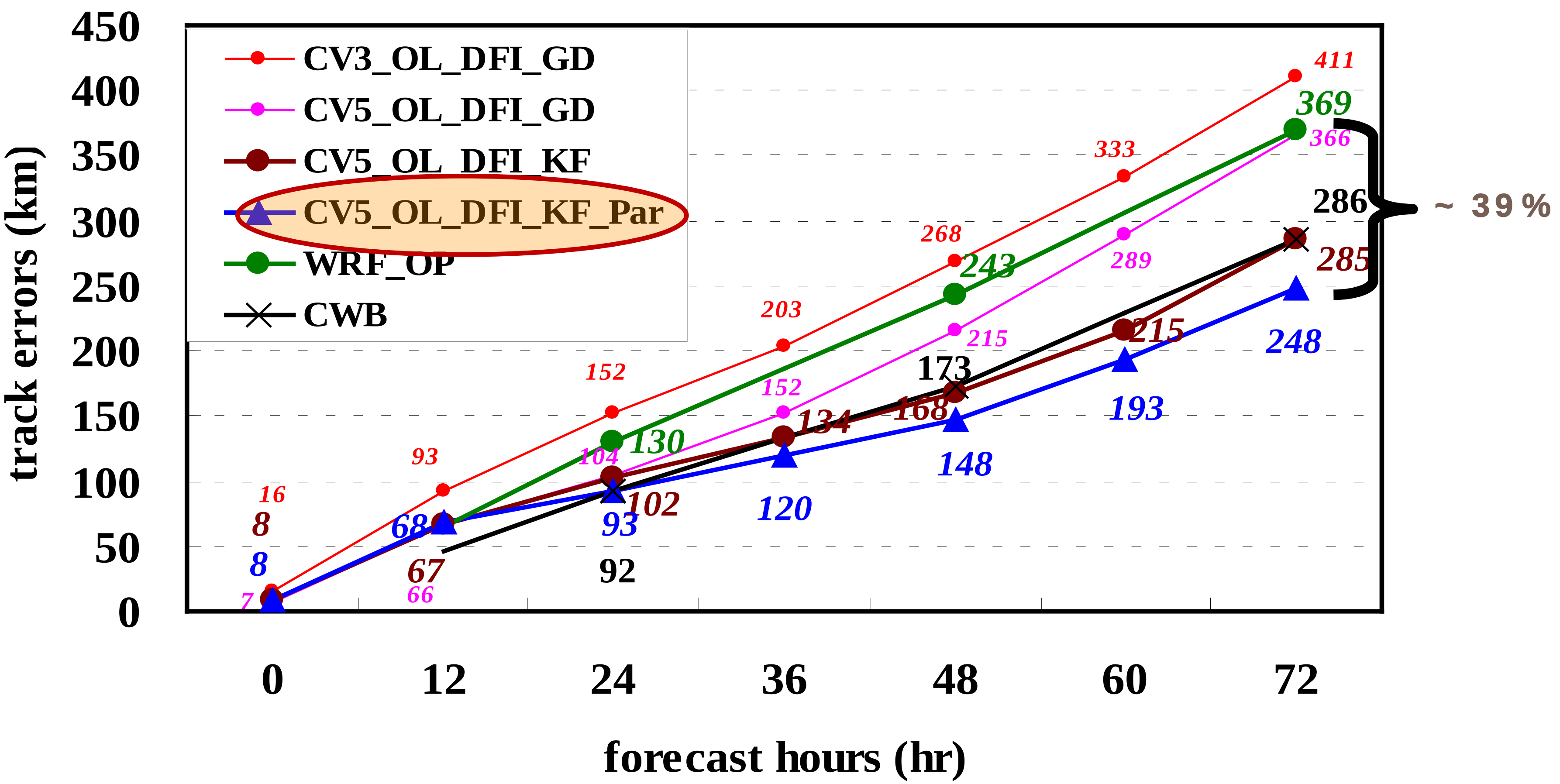


The mean error of the composite analysis of full cycle (left) and partial cycle (right) experiment from 78 cases for 700 hPa temperature

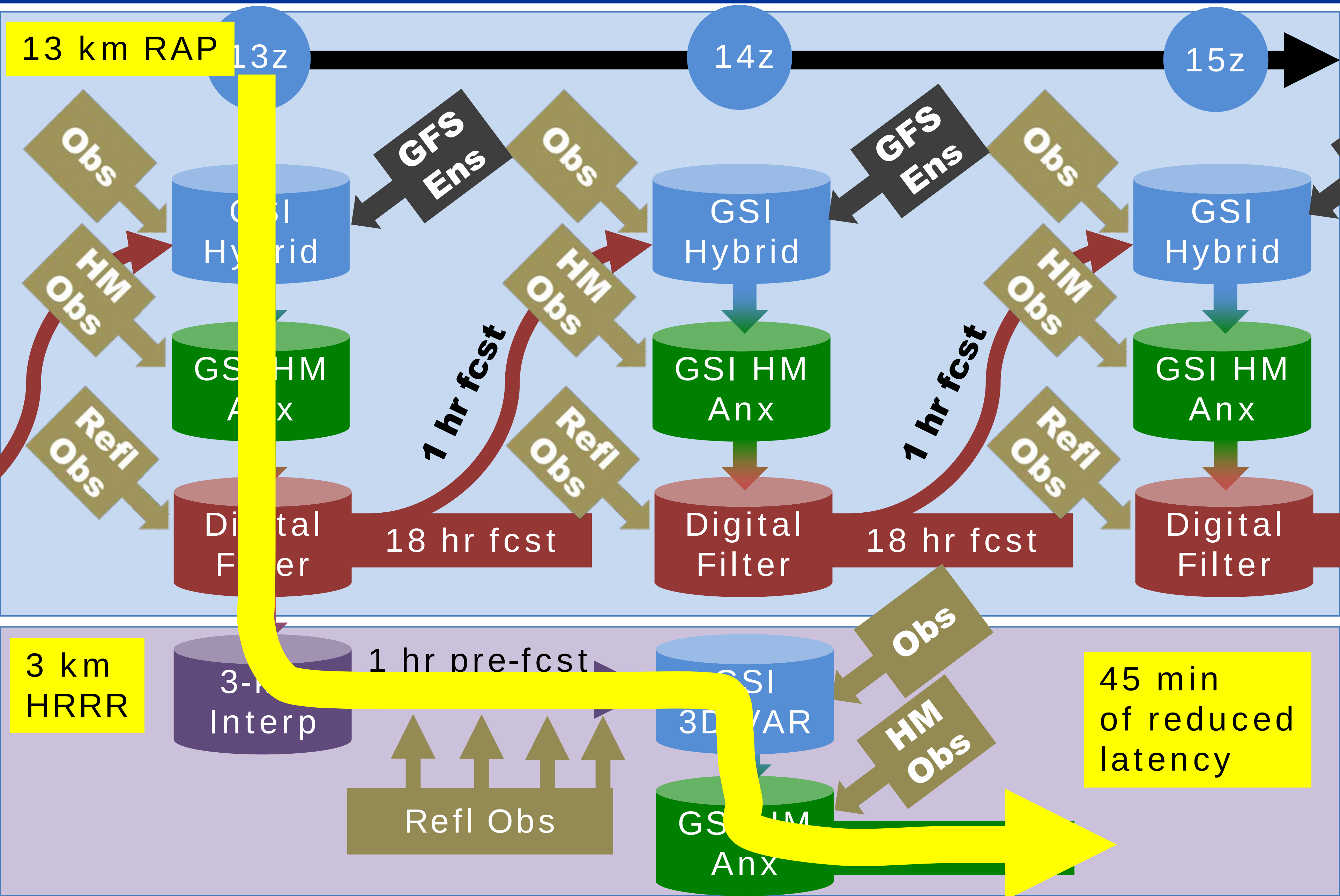
To remove the accumulated bias over data sparse area.

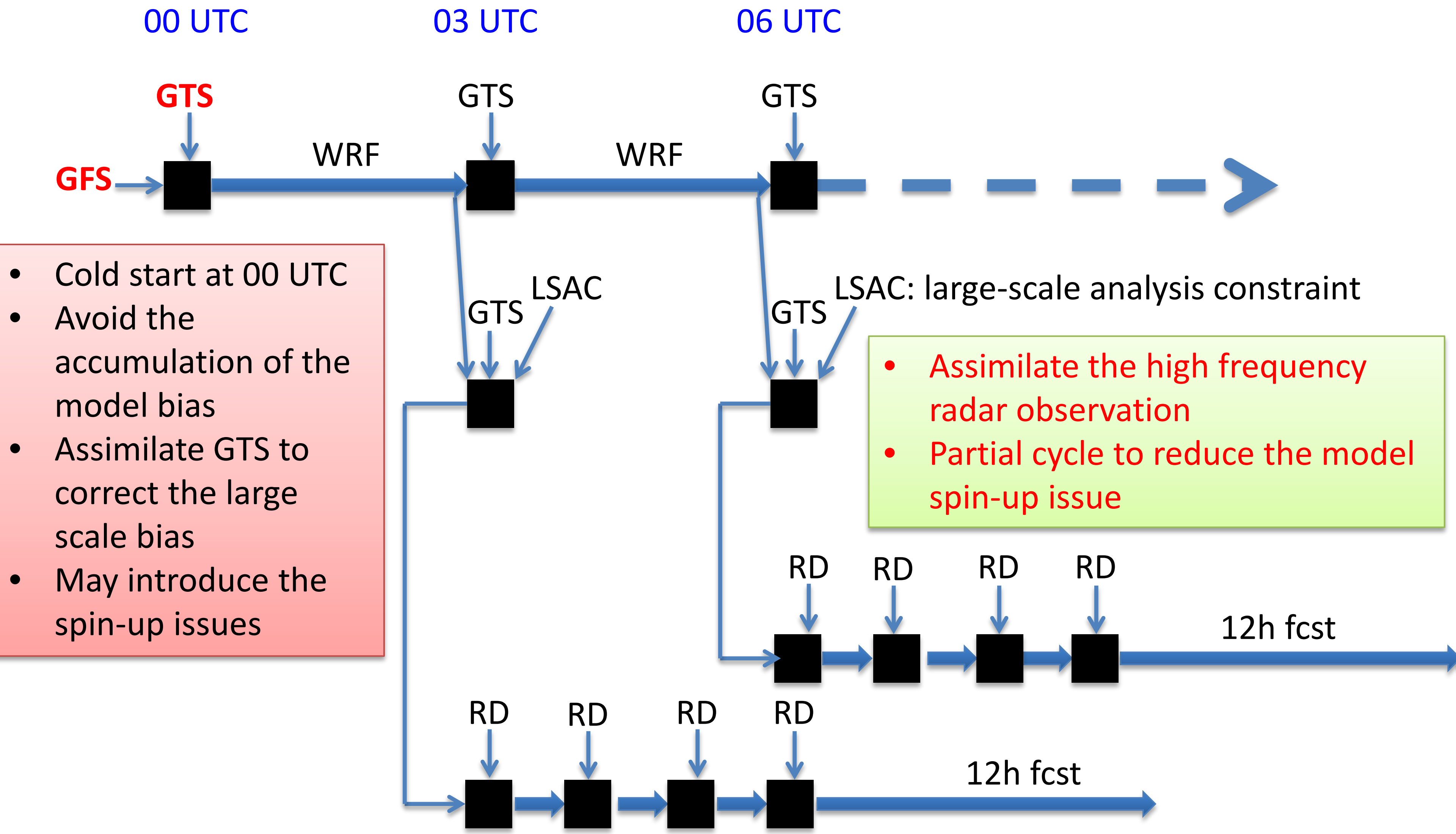
Hsiao et al. (2010)

Mean typhoon track errors for 247 retrospective case

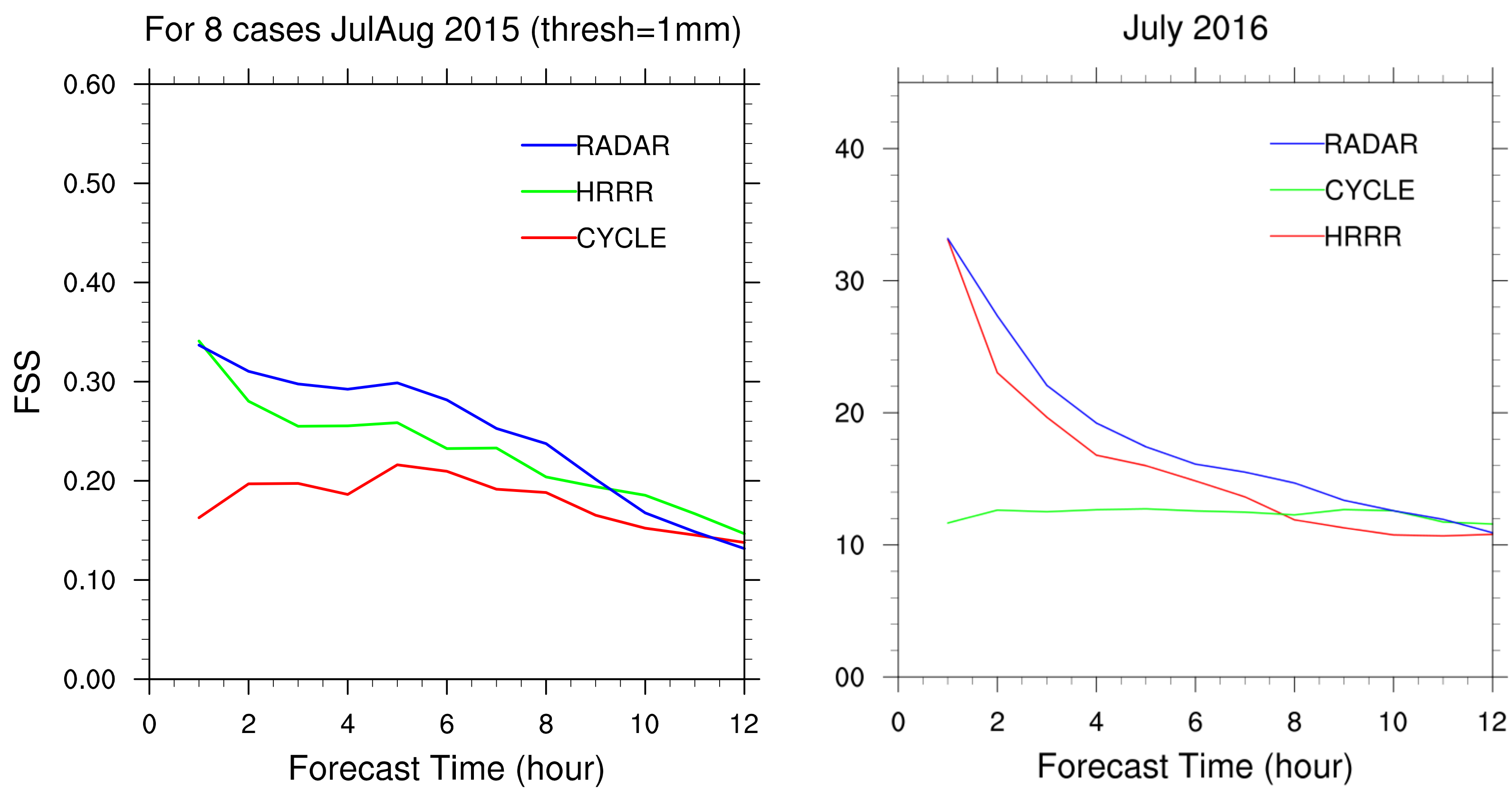


NOAA HRRR Initialization





SHORT-TERM EXPLICIT PREDICTION (STEP) PROGRAM/NCAR



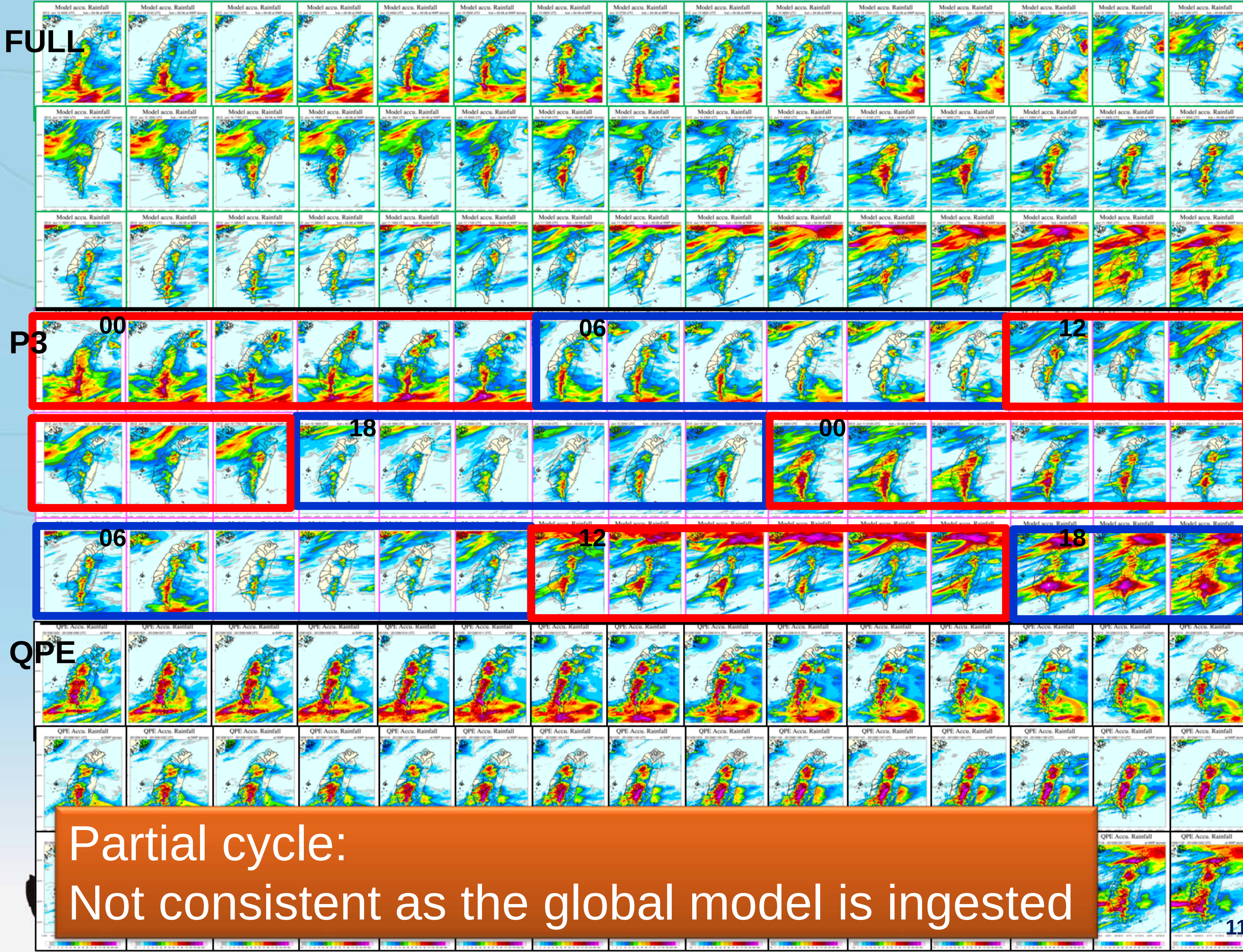
Tong, W. Et al. 2016: Design strategies of an hourly update 3DVAR data assimilation system for improved convective forecasting, Weather and forecasting

About the DA strategy …

	Pros	Cons
Full cycle	• Limited spin-up	• Accumulate model error
Cold start Partial cycle	• Spin-up • Less spin-up	• Reset the error from large scale model
Conventional observation	• Observe the model state variable	• Not real time • Low Spatial & temporal resolution
Radar observation	• Hydrometer and wind • realtime	• Challenge to handle the hydrometer, especially large gradient in cost fun
Satellite obs	• …	• …

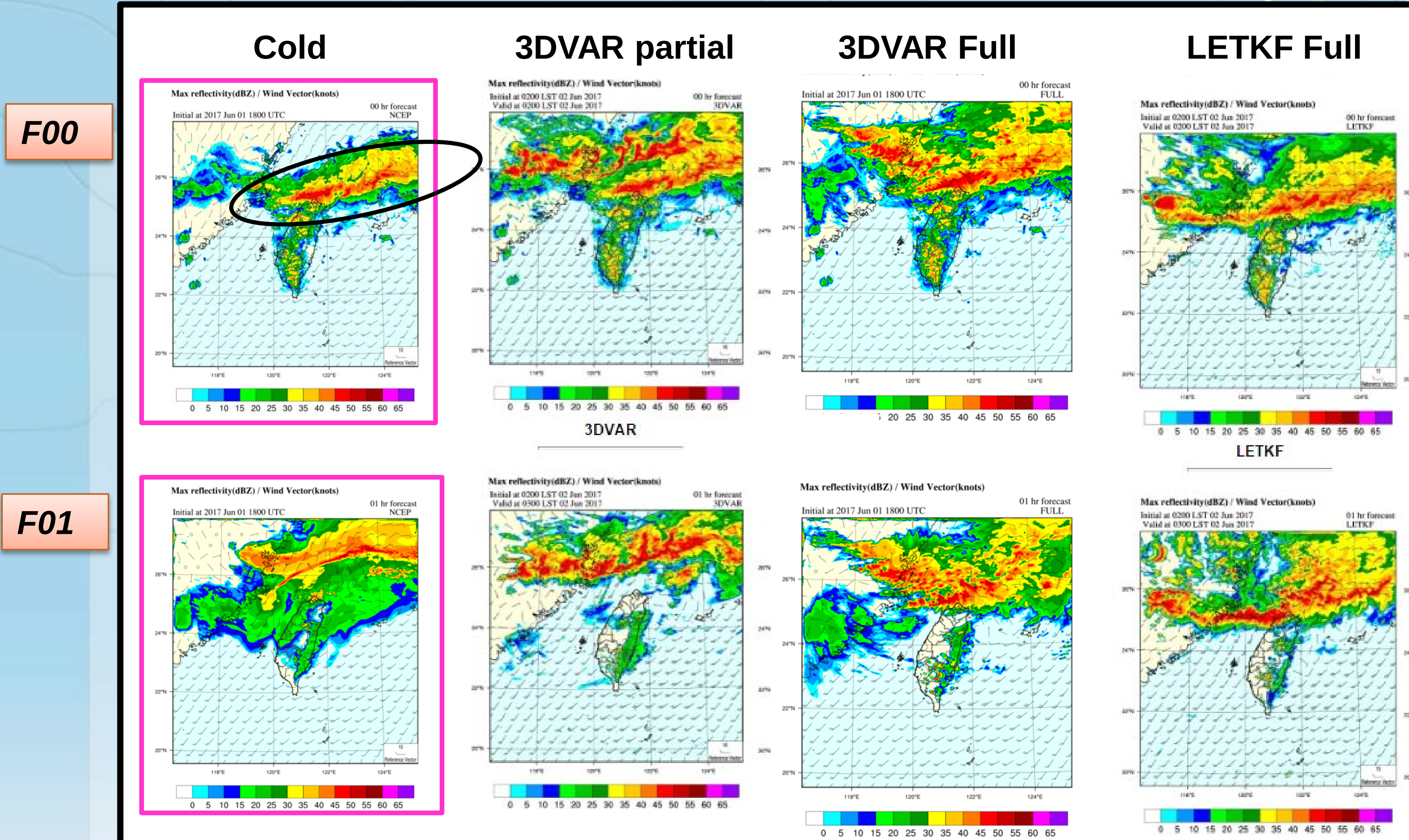
Easy maintain:cost/benefit in operational

Global model may hurt……

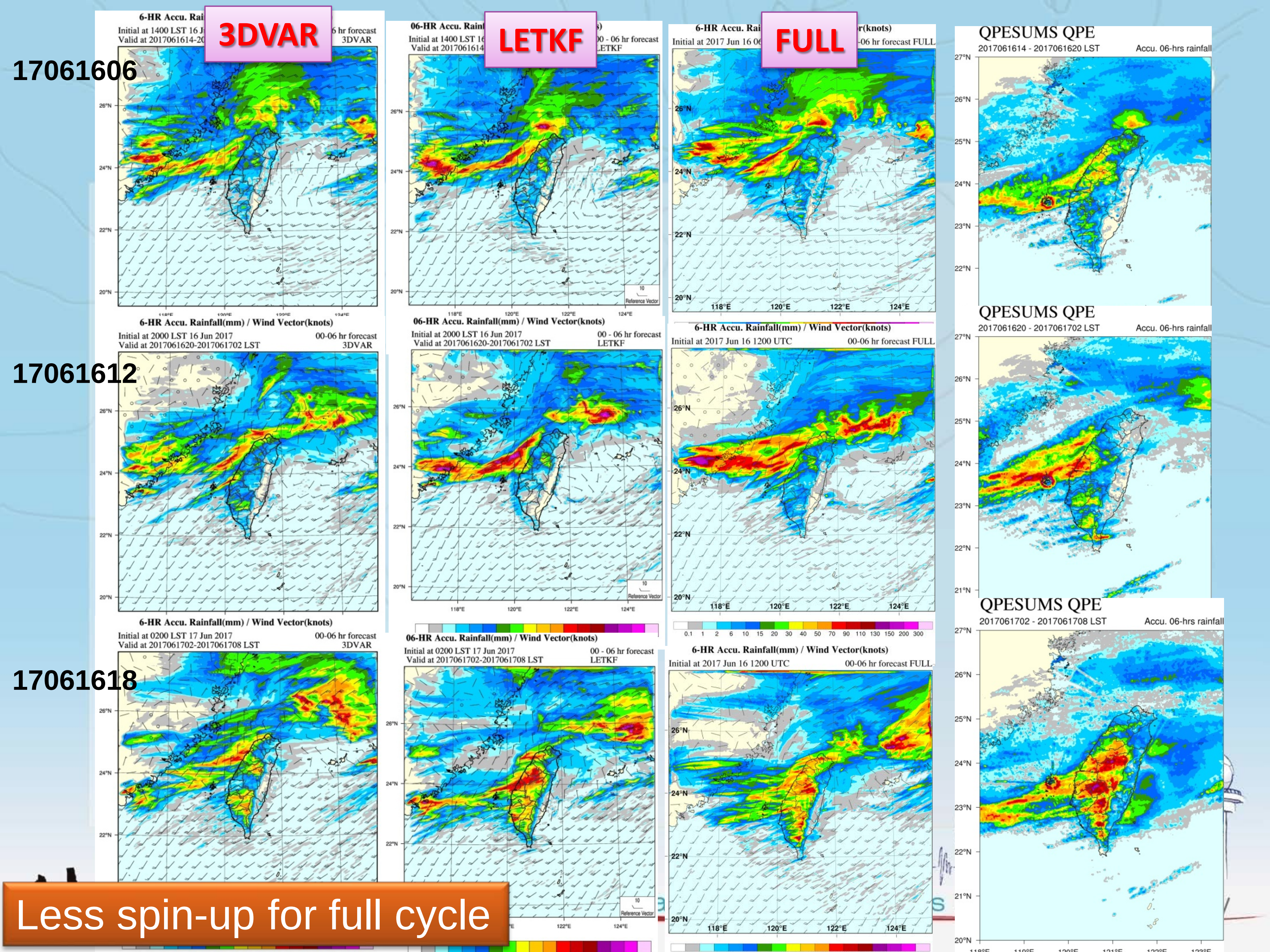


Partial cycle:
Not consistent as the global model is ingested

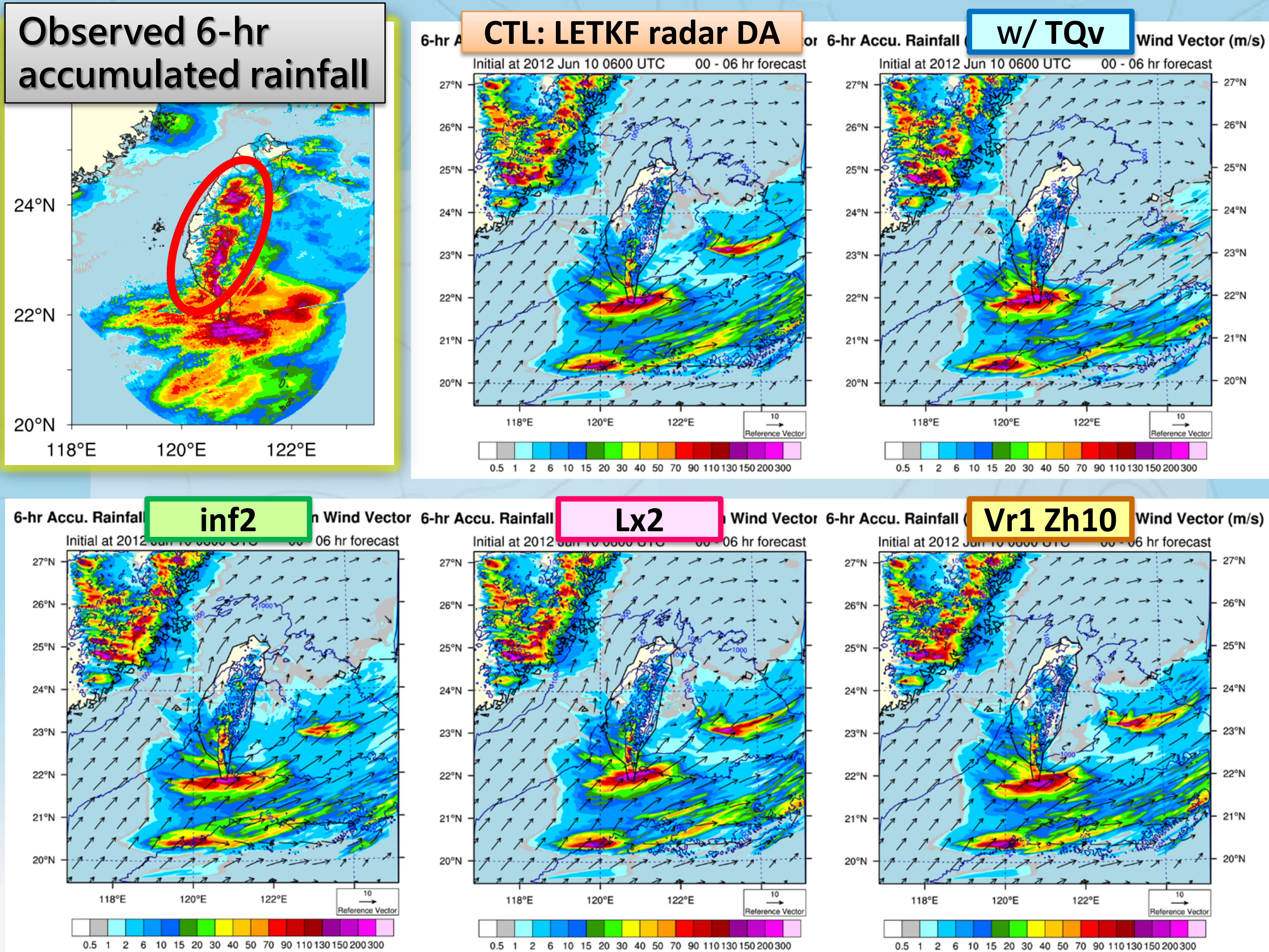
20170601 18



- The global model (more dynamic balance) phase error can not be corrected by the limited radar observations.
- On the other hand, **the mesoscale is doing very well**


3DVAR
LETKF
FULL
17061606
17061612
17061618
6-HR Accu. Rainfall(mm) / Wind Vector(knots)
Initial at 2000 LST 16 Jun 2017
Valid at 2017061620-2017061702 LST
00-06 hr forecast 3DVAR
06-HR Accu. Rainfall(mm) / Wind Vector(knots)
00 - 06 hr forecast LETKF
Initial at 2017 Jun 16 1200 UTC
00-06 hr forecast FULL
Initial at 0200 LST 17 Jun 2017
Valid at 2017061702-2017061708 LST
QPESUMS QPE
2017061614 - 2017061620 LST
2017061620 - 2017061702 LST
2017061702 - 2017061708 LST
Accu. 06-hrs rainfall
0.1 1 2 6 10 15 20 30 40 50 70 90 110 130 150 200 300
Less spin-up for full cycle

Sometimes,
convective scale model just can’t do anything …



Observed 6-hr accumulated rainfall
24°N
22°N
20°N
118°E
120°E
122°E
CTL: LETKF radar DA
w/ TQv
inf2
Lx2
Vr1 Zh10
6-hr Accu. Rainfall
Wind Vector (m/s)
Initial at 2012 Jun 10 0600 UTC
00 - 06 hr forecast
27°N
26°N
25°N
24°N
23°N
22°N
21°N
20°N
118°E
120°E
122°E
10
Reference Vector
0.5 1 2 6 10 15 20 30 40 50 70 90 110 130 150 200 300

To take the advantage from the regional and global model

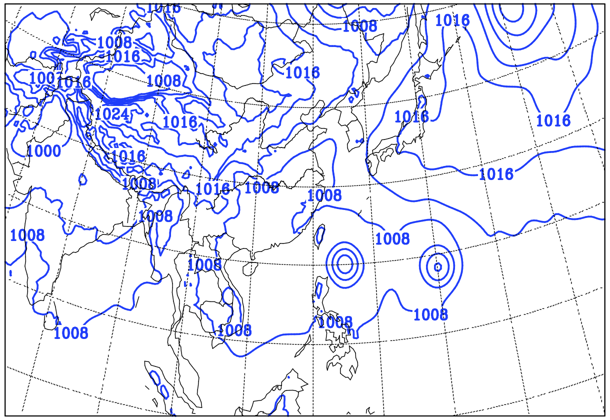
Blend (Yang 2005, Hsiao et al. 2016) the regional (r) and global (g) using the low-pass Raymond 6th order tangent implicit filter (Raymond and Garder 1991)

$$X_{bld} = X_r + \overline{X_g}^{sf} - \overline{X_r}^{sf}$$

A low-pass Raymond 6th order tangent implicit filter (Raymond and Garder 1991)

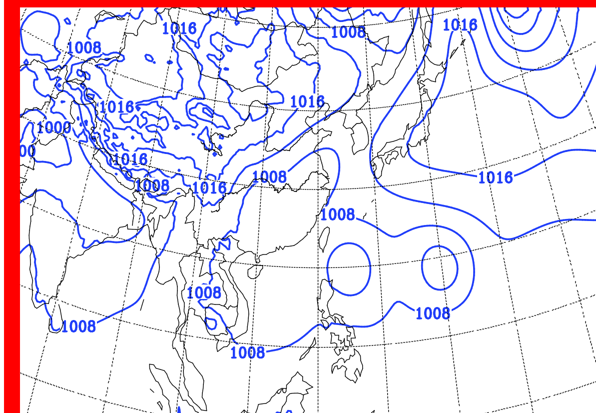
GFS

SEA LEVEL PRESSURE (hPa) -- GFS



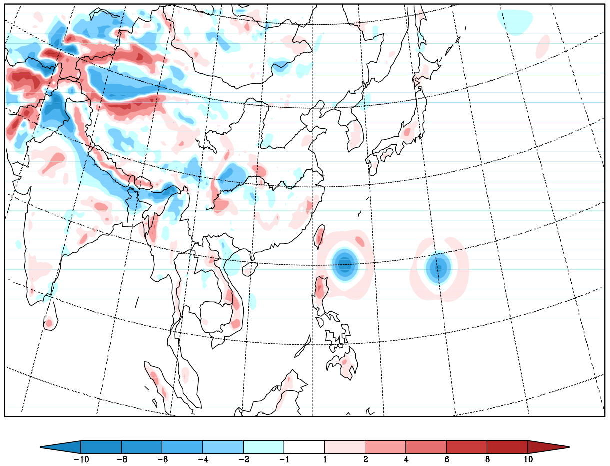
GFS (>1200km)

SEA LEVEL PRESSURE (hPa) -- GFS(L)



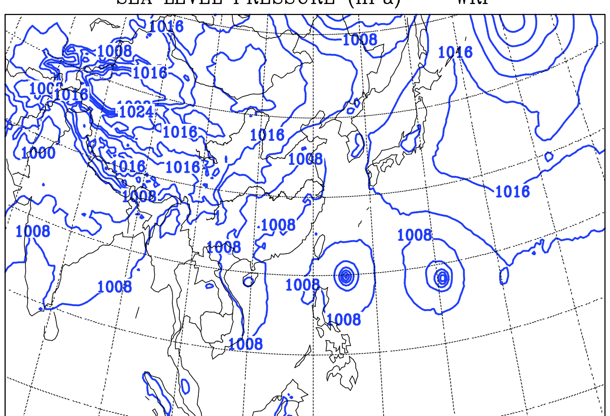
GFS (difference)

SEA LEVEL PRESSURE (hPa) -- GFS(S)



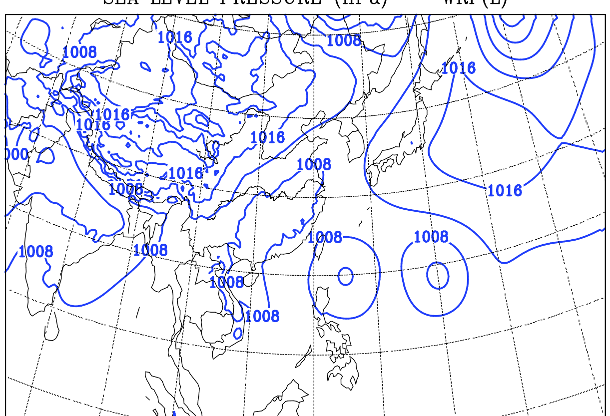
WRF

SEA LEVEL PRESSURE (hPa) -- WRF



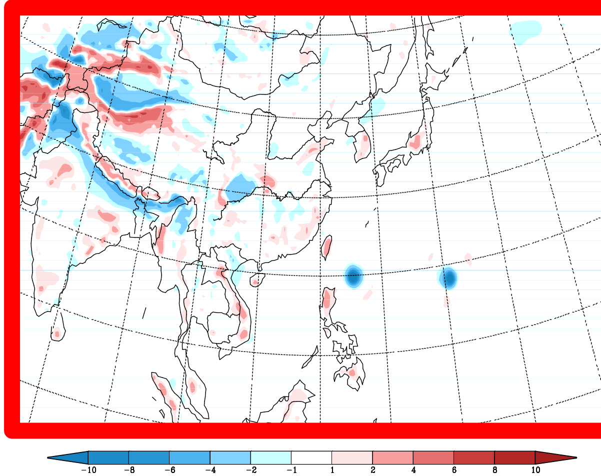
WRF (>1200km)

SEA LEVEL PRESSURE (hPa) -- WRF(L)

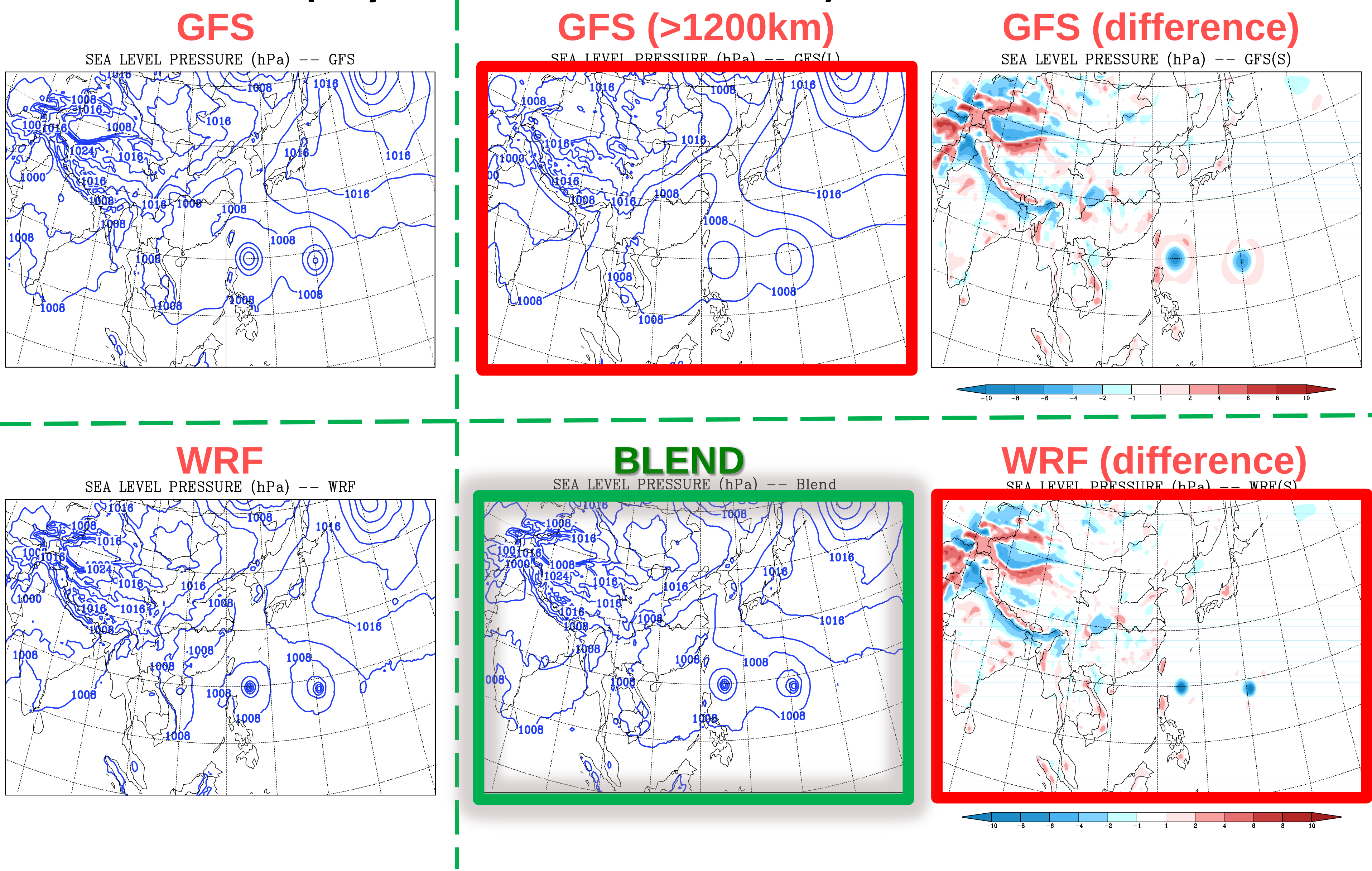


WRF (difference)

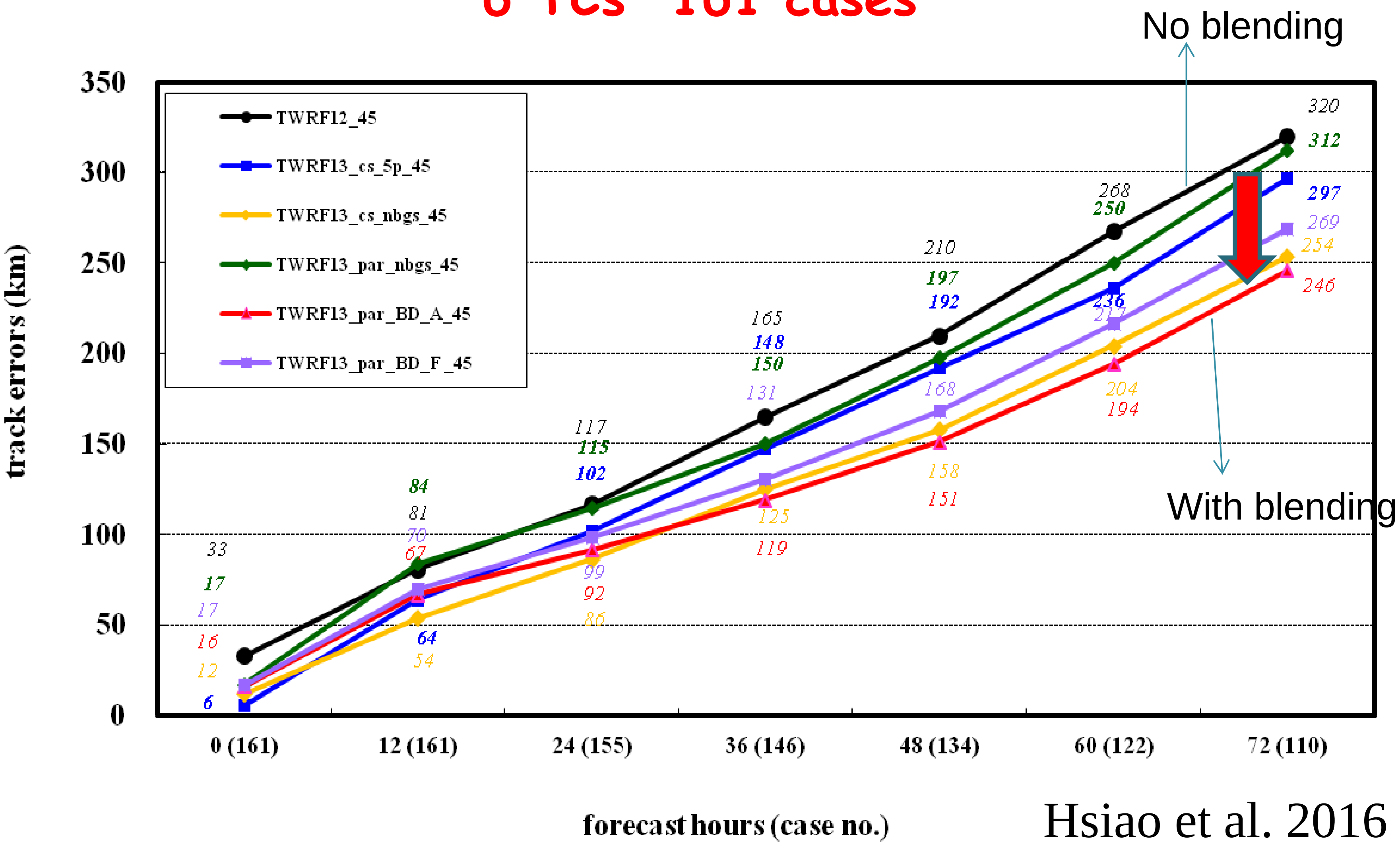
SEA LEVEL PRESSURE (hPa) -- WRF(S)



A low-pass Raymond 6th order tangent implicit filter (Raymond and Garder 1991)

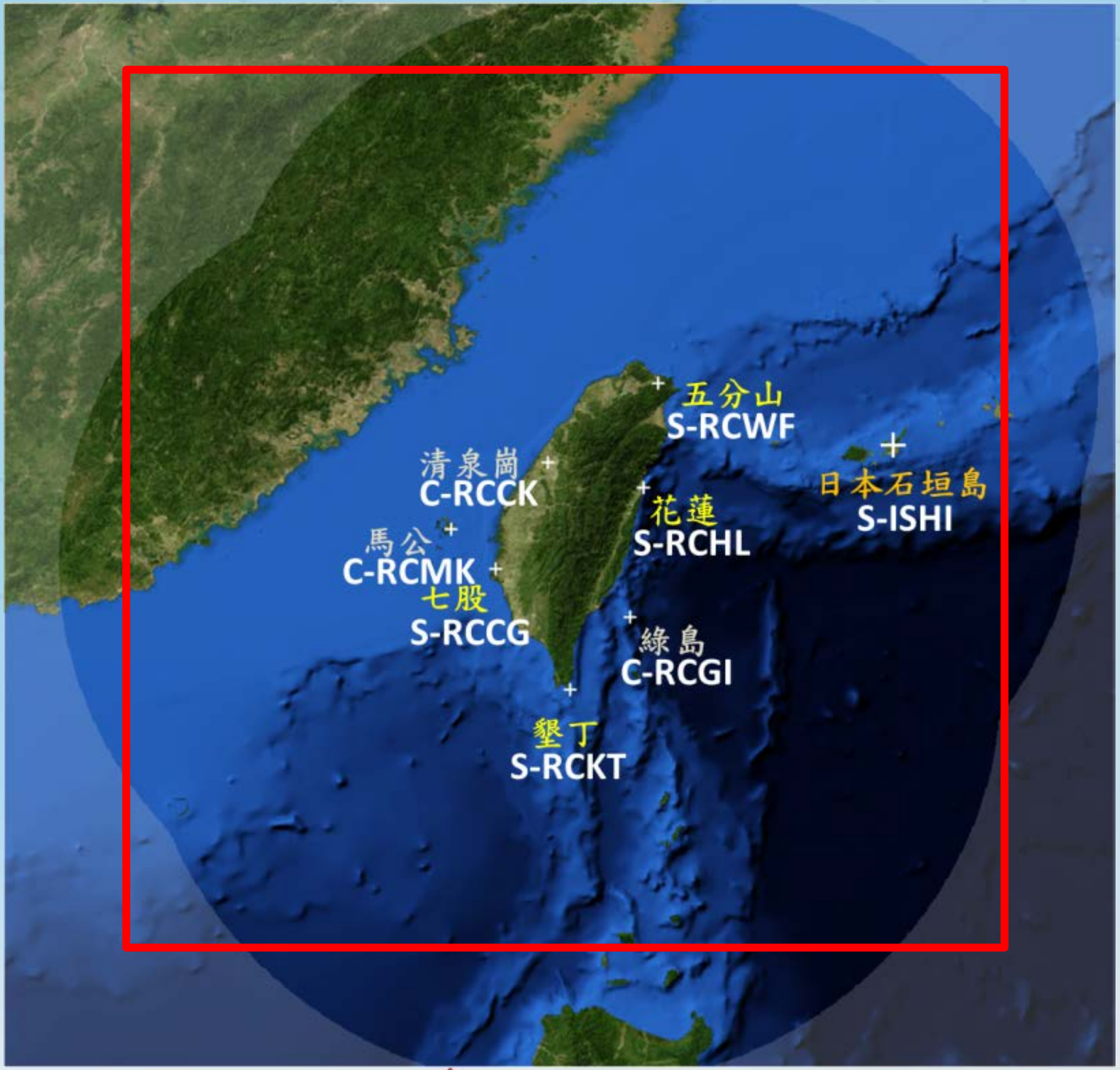


TC track 72hrs forecast errors for TWRF1.3 to 2012
6 TCs 161 cases



Hsiao et al. 2016

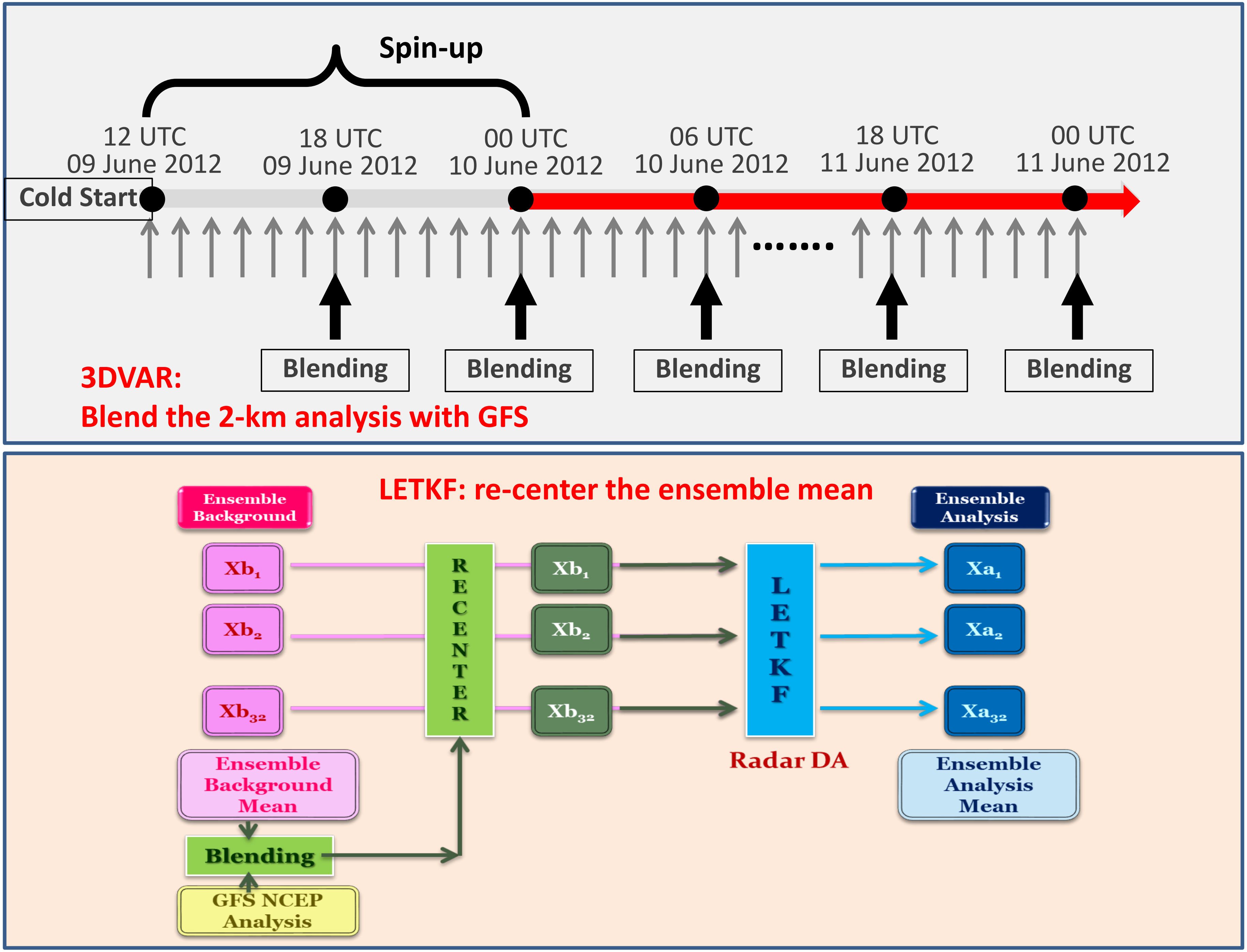
How about apply to convective scale DA?



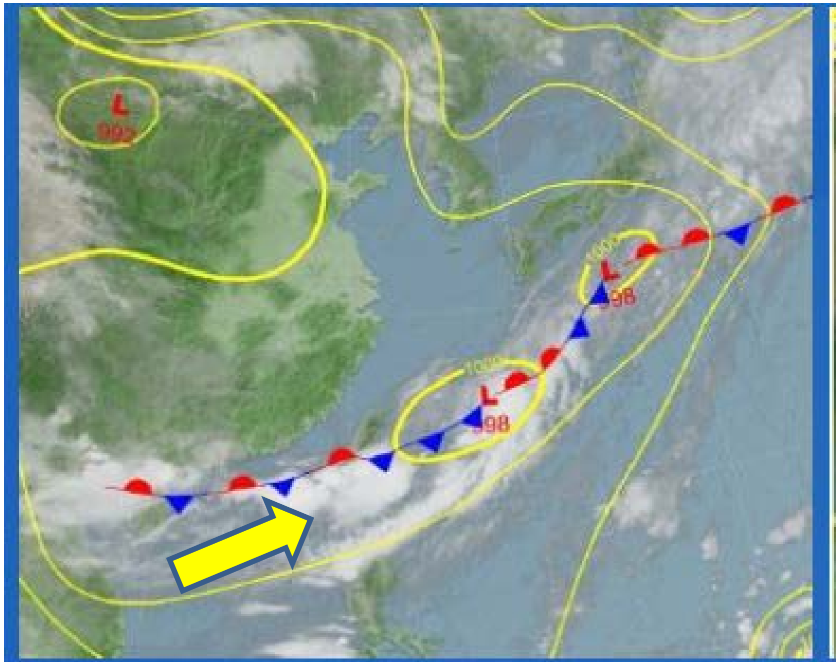
- 2-km resolution
  - Hourly updated, extended to 12-hr forecast
  - Full cycle for 3DVAR/LETKF
  - Assimilate 4-S band, 3-C band dBZ, Vr
- 52 model levels
- 20-hPa pressure top

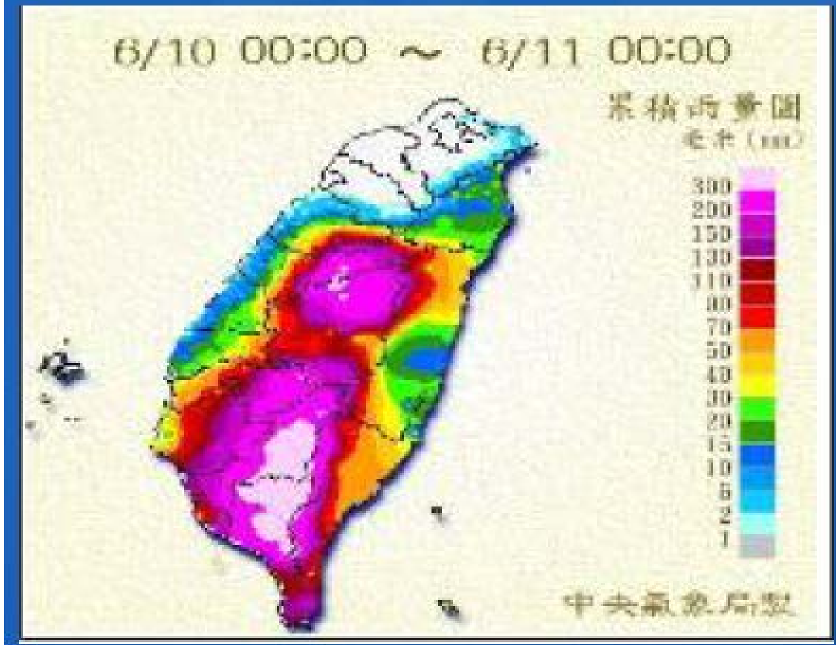
Physics package:

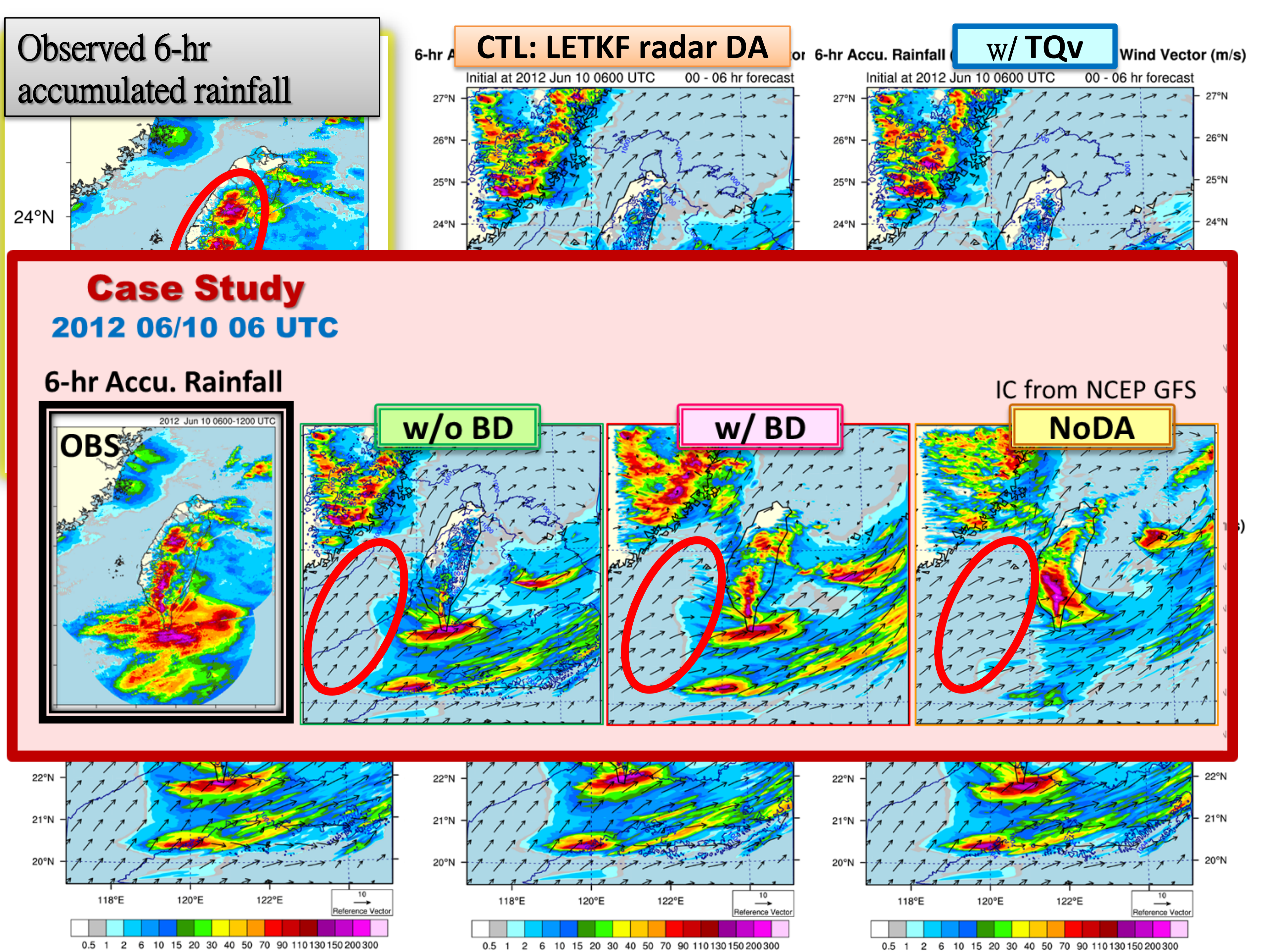
- No CuP
- Long/short wave Radiation: RRTMG
- MPS: Goddard scheme
- PBL: YSU
- Land: NOAH



Spin-up
12 UTC 09 June 2012
18 UTC 09 June 2012
00 UTC 10 June 2012
06 UTC 10 June 2012
18 UTC 11 June 2012
00 UTC 11 June 2012
Cold Start
Blending
Blending
Blending
Blending
Blending
3DVAR:
Blend the 2-km analysis with GFS
LETKF: re-center the ensemble mean
Ensemble Background
Ensemble Analysis
Xb_1
Xb_2
Xb_{32}
RECENTER
Xb_1
Xb_2
Xb_{32}
LETKF
Xa_1
Xa_2
Xa_{32}
Radar DA
Ensemble Background Mean
Ensemble Analysis Mean
Blending
GFS NCEP Analysis


L
992


6/10 00:00 ～ 6/11 00:00
累積雨量圖
毫米 (mm)
300
200
150
130
110
90
70
50
40
30
20
15
10
6
2
1
中央氣象局製



Observed 6-hr accumulated rainfall
24°N
CTL: LETKF radar DA
w/ TQv
6-hr Accu. Rainfall
Wind Vector (m/s)
Initial at 2012 Jun 10 0600 UTC
00 - 06 hr forecast
27°N
26°N
25°N
24°N
Case Study
2012 06/10 06 UTC
6-hr Accu. Rainfall
IC from NCEP GFS
OBS
2012 Jun 10 0600-1200 UTC
w/o BD
w/ BD
NoDA
22°N
21°N
20°N
118°E
120°E
122°E
10
Reference Vector
0.5 1 2 6 10 15 20 30 40 50 70 90 110 130 150 200 300

The spatial filter

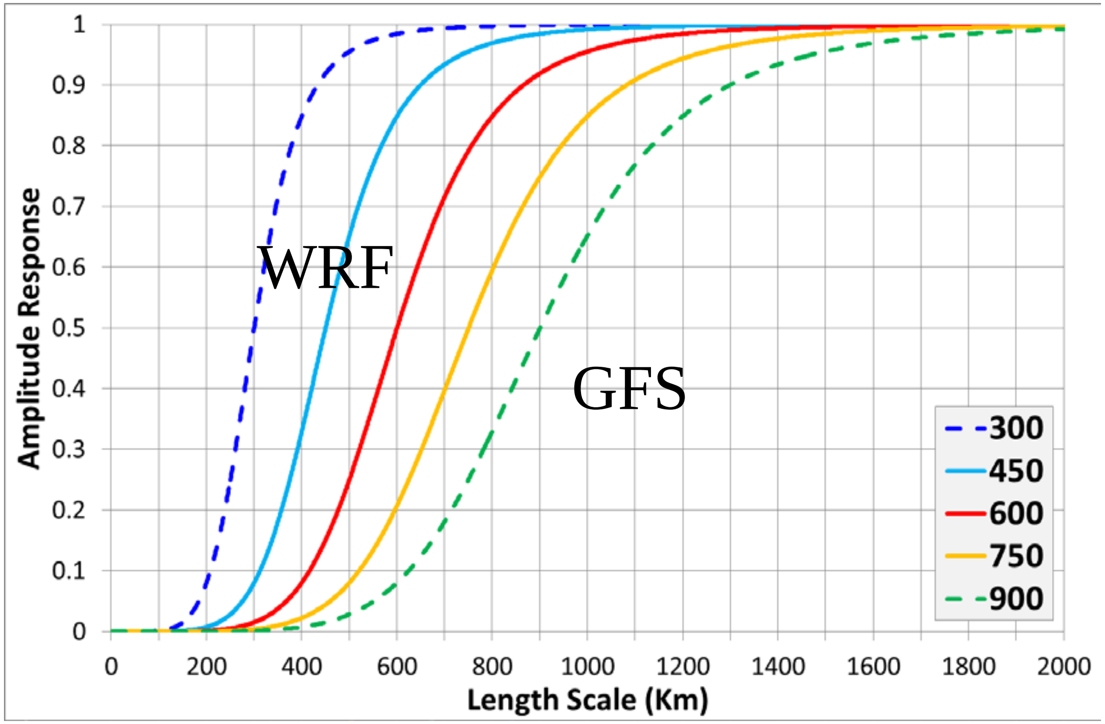
- Amplitude response function:

$$H(L) = \left[1 + \varepsilon \tan^6 \left(\frac{\pi \delta x}{L} \right) \right]^{-1}$$

$$\varepsilon = \tan^{-6} \left(\frac{\pi \delta x}{L_x} \right)$$

- ε is the filter parameter; δx is grid spacing
- L_x is Cut-off Length Scale (CLS)

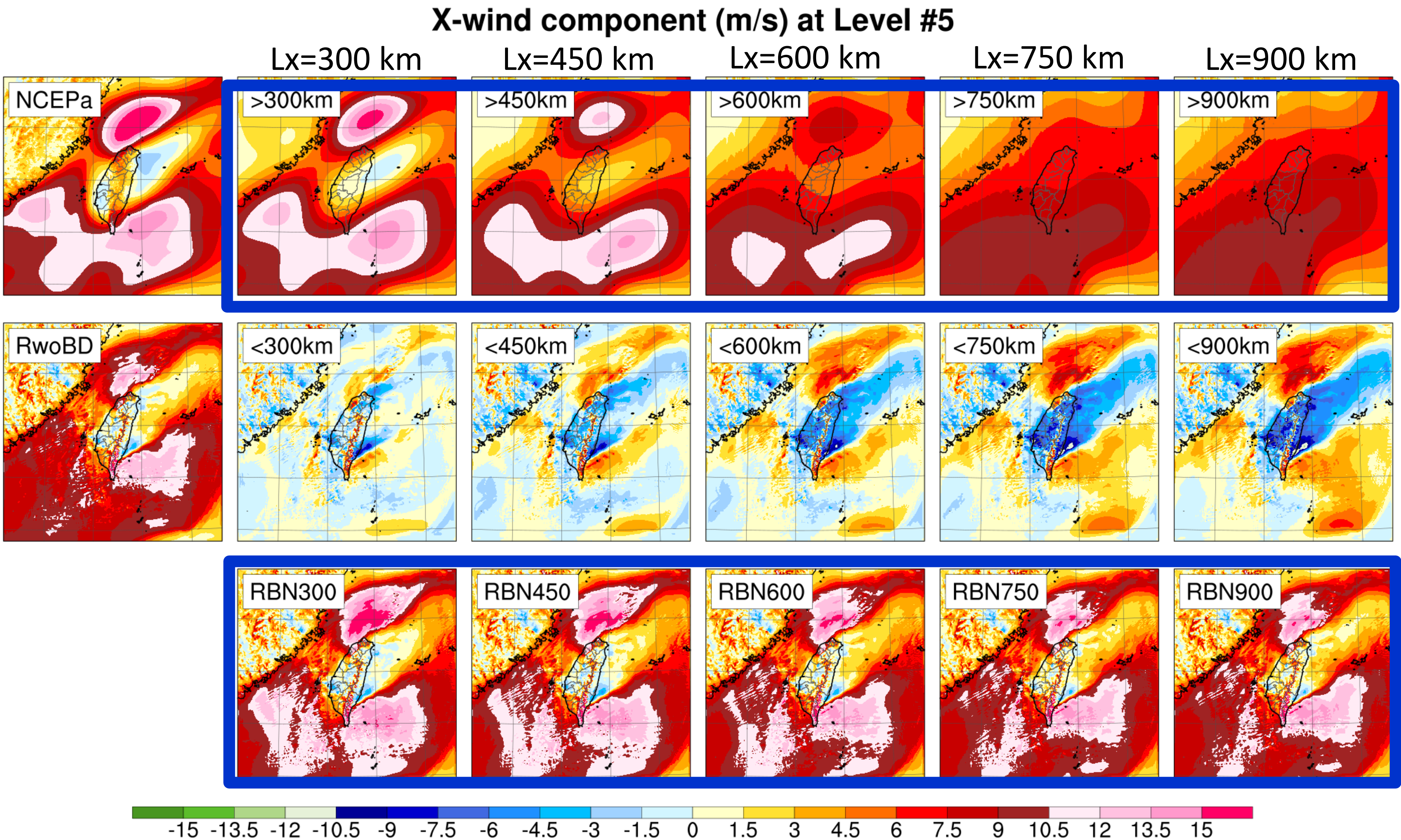
Raymond filter response function

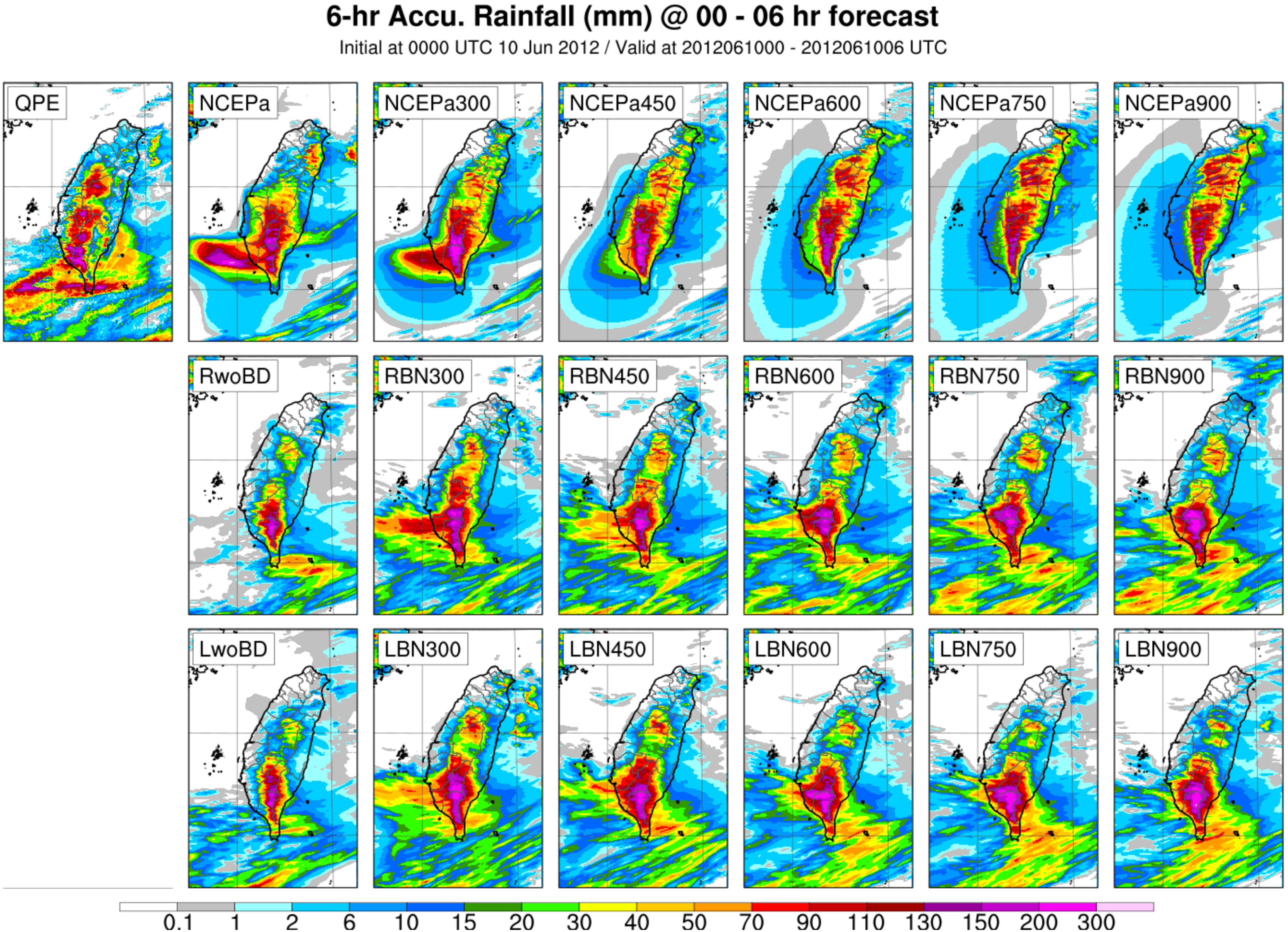


- Blended fields
  - U, V, T, QVAPOR, PH, P, MU,
  - U10, V10, T2, Q2, PSFC, TH2
- Smaller Cut-off Length Scale, more GFS

EXP	Description
RwoBD/LwoBD	Without Blending Method
RBN300/LBN300	Blending NCEP GFS analysis at CLS = 300 km
RBN450/LBN450	Blending NCEP GFS analysis at CLS = 450 km
RBN600/LBN600	Blending NCEP GFS analysis at CLS = 600 km
RBN750/LBN750	Blending NCEP GFS analysis at CLS = 750 km
NCEPa	Initialized by NCEP GFS
NCEPa300	Initialized by NCEP GFS with CLS>300 km
NCEPa450	Initialized by NCEP GFS with CLS>450 km
NCEPa600	Initialized by NCEP GFS with CLS>600 km
NCEPa750	Initialized by NCEP GFS with CLS>750 km

Note: CLS: Cut-off length scale, L is for LETKF, R is for 3DVAR

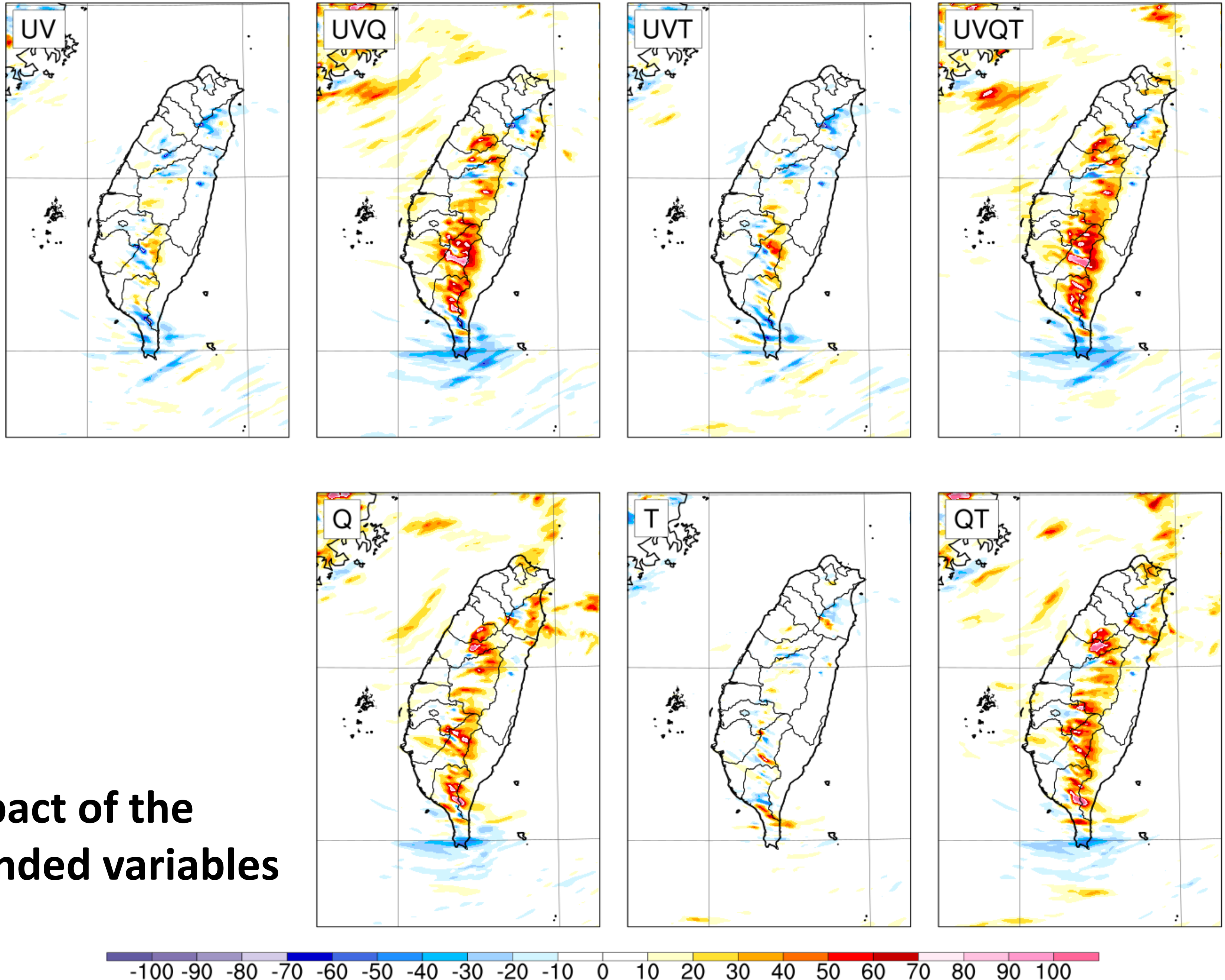

X-wind component (m/s) at Level #5
Lx=300 km
Lx=450 km
Lx=600 km
Lx=750 km
Lx=900 km
NCEPa
>300km
>450km
>600km
>750km
>900km
RwoBD
<300km
<450km
<600km
<750km
<900km
RBN300
RBN450
RBN600
RBN750
RBN900
-15 -13.5 -12 -10.5 -9 -7.5 -6 -4.5 -3 -1.5 0 1.5 3 4.5 6 7.5 9 10.5 12 13.5 15



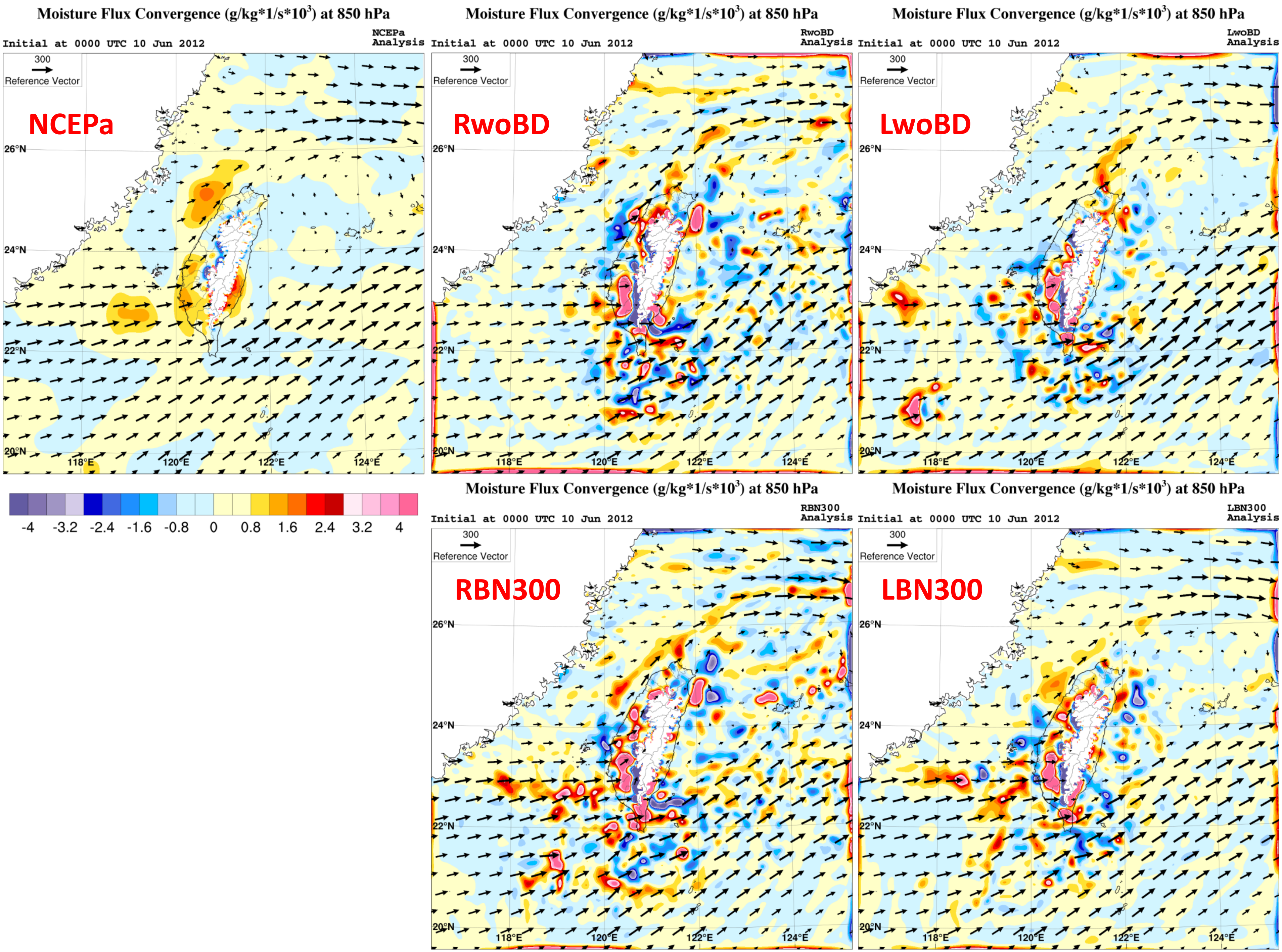
6-hr Accu. Rainfall (mm) @ 00 - 06 hr forecast
Initial at 0000 UTC 10 Jun 2012 / Valid at 2012061000 - 2012061006 UTC
QPE
NCEPa
NCEPa300
NCEPa450
NCEPa600
NCEPa750
NCEPa900
RwoBD
RBN300
RBN450
RBN600
RBN750
RBN900
LwoBD
LBN300
LBN450
LBN600
LBN750
LBN900
0.1 1 2 6 10 15 20 30 40 50 70 90 110 130 150 200 300

Difference of 6-hr Accu. Rainfall (mm) @ 00 - 06 hr forecast

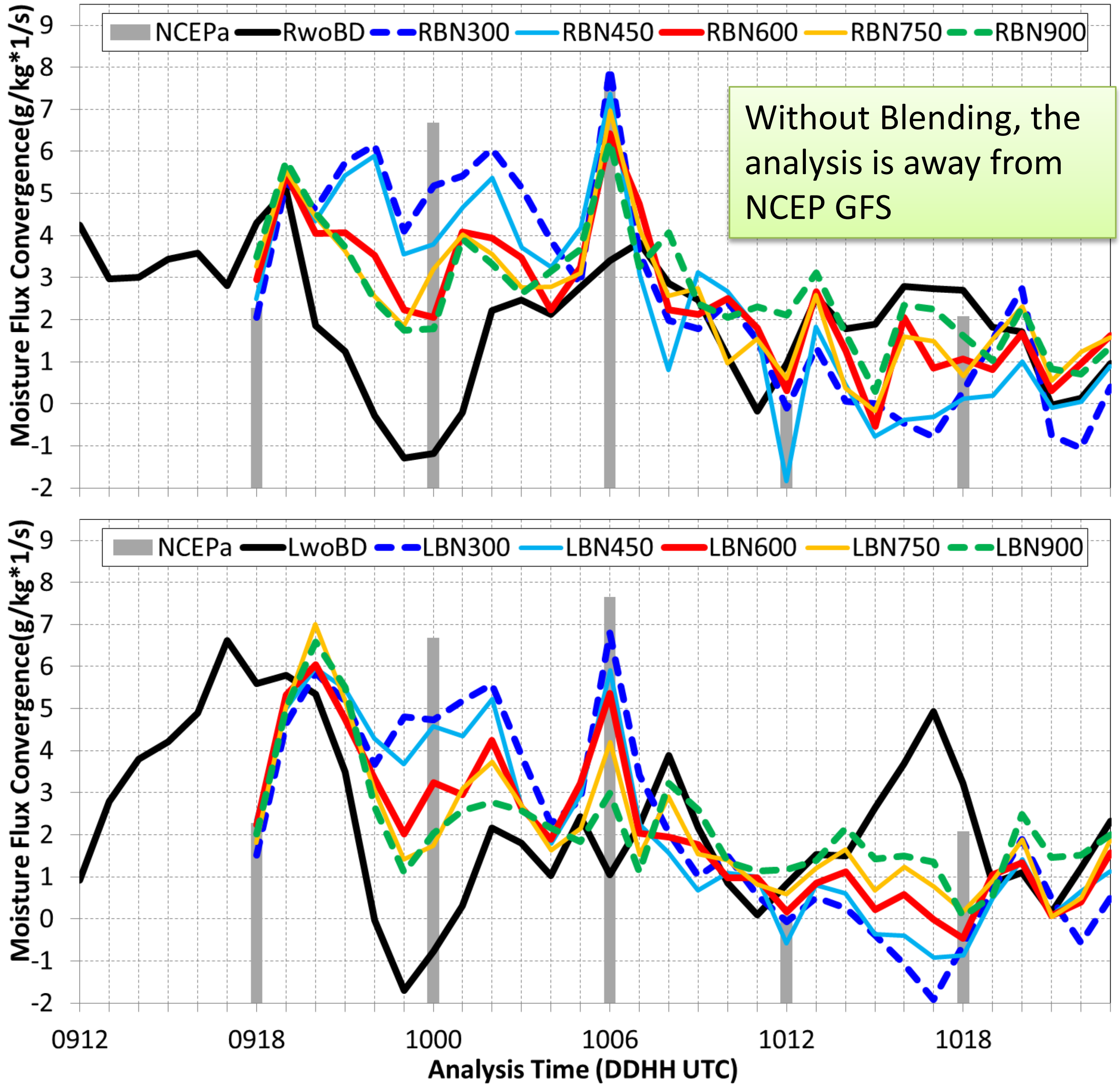
Initial at 0600 UTC 10 Jun 2012 / Valid at 2012061006 - 2012061012 UTC



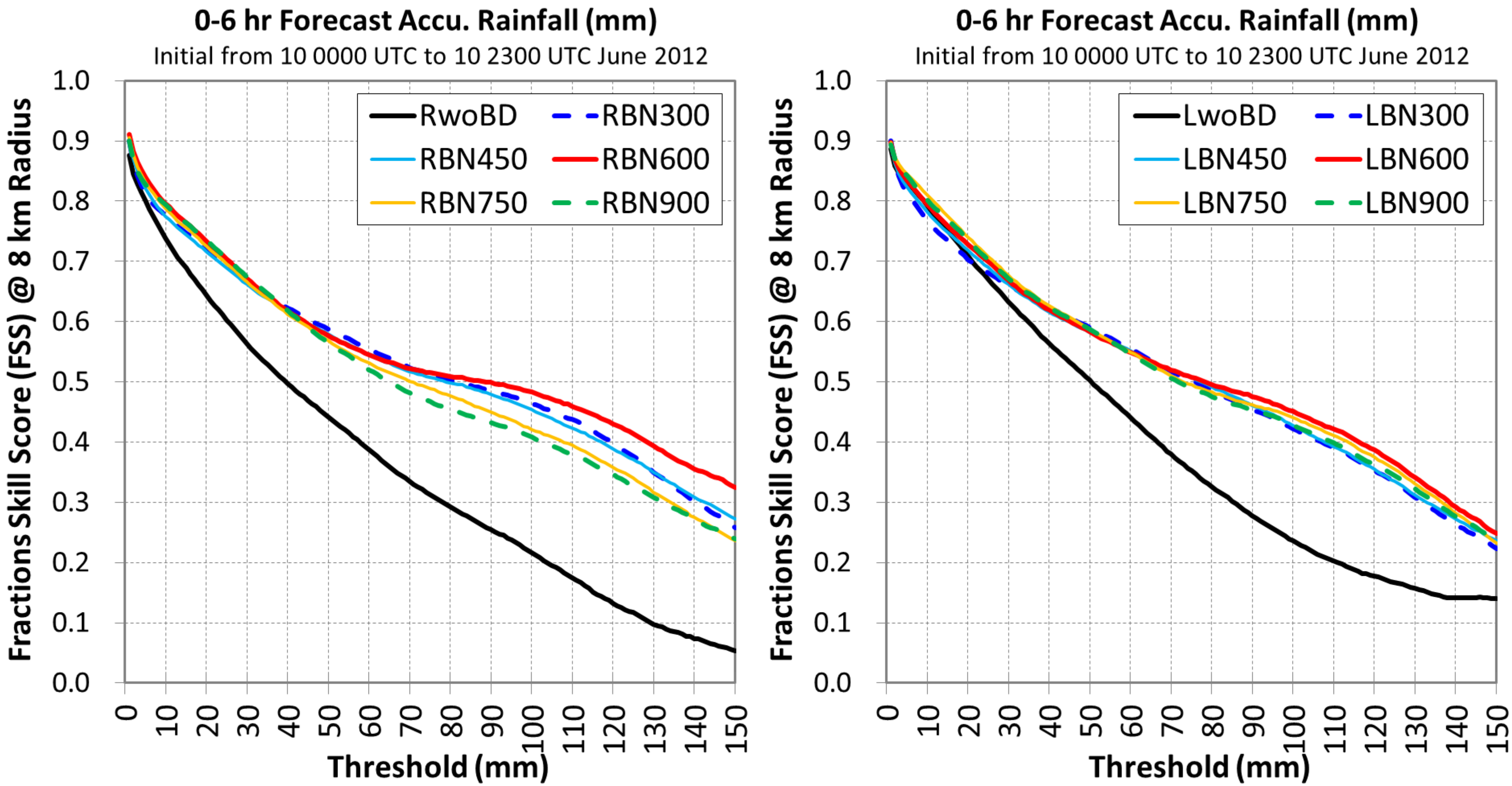
Impact of the blended variables



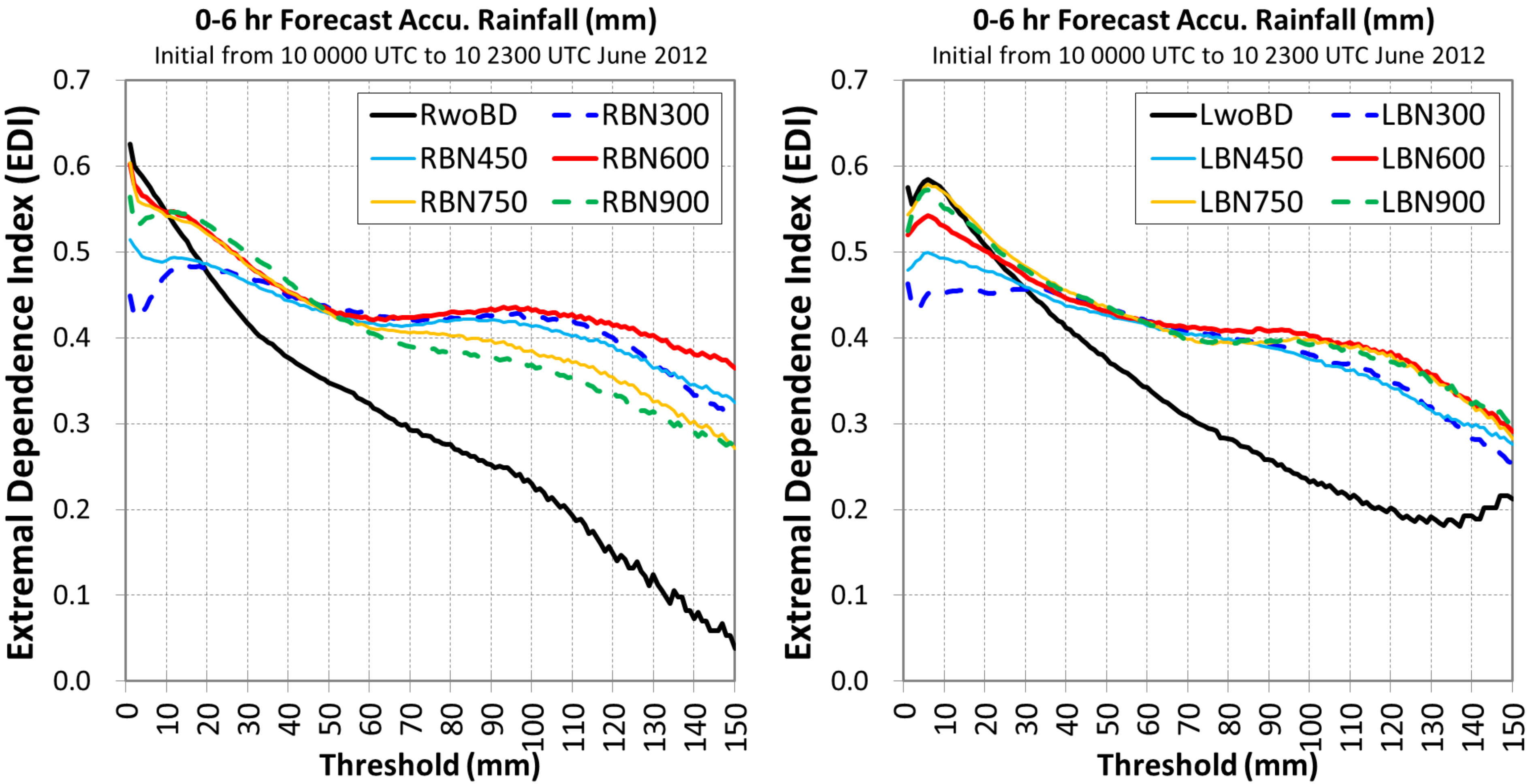
Moisture Flux Convergence (g/kg*1/s*10^3) at 850 hPa
Initial at 0000 UTC 10 Jun 2012
NCEPa Analysis
300
Reference Vector
NCEPa
26°N
24°N
22°N
20°N
118°E
120°E
122°E
124°E
Moisture Flux Convergence (g/kg*1/s*10^3) at 850 hPa
Initial at 0000 UTC 10 Jun 2012
RwoBD Analysis
RwoBD
Moisture Flux Convergence (g/kg*1/s*10^3) at 850 hPa
Initial at 0000 UTC 10 Jun 2012
LwoBD Analysis
LwoBD
Moisture Flux Convergence (g/kg*1/s*10^3) at 850 hPa
Initial at 0000 UTC 10 Jun 2012
RBN300 Analysis
RBN300
Moisture Flux Convergence (g/kg*1/s*10^3) at 850 hPa
Initial at 0000 UTC 10 Jun 2012
LBN300 Analysis
LBN300
-4 -3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2 4

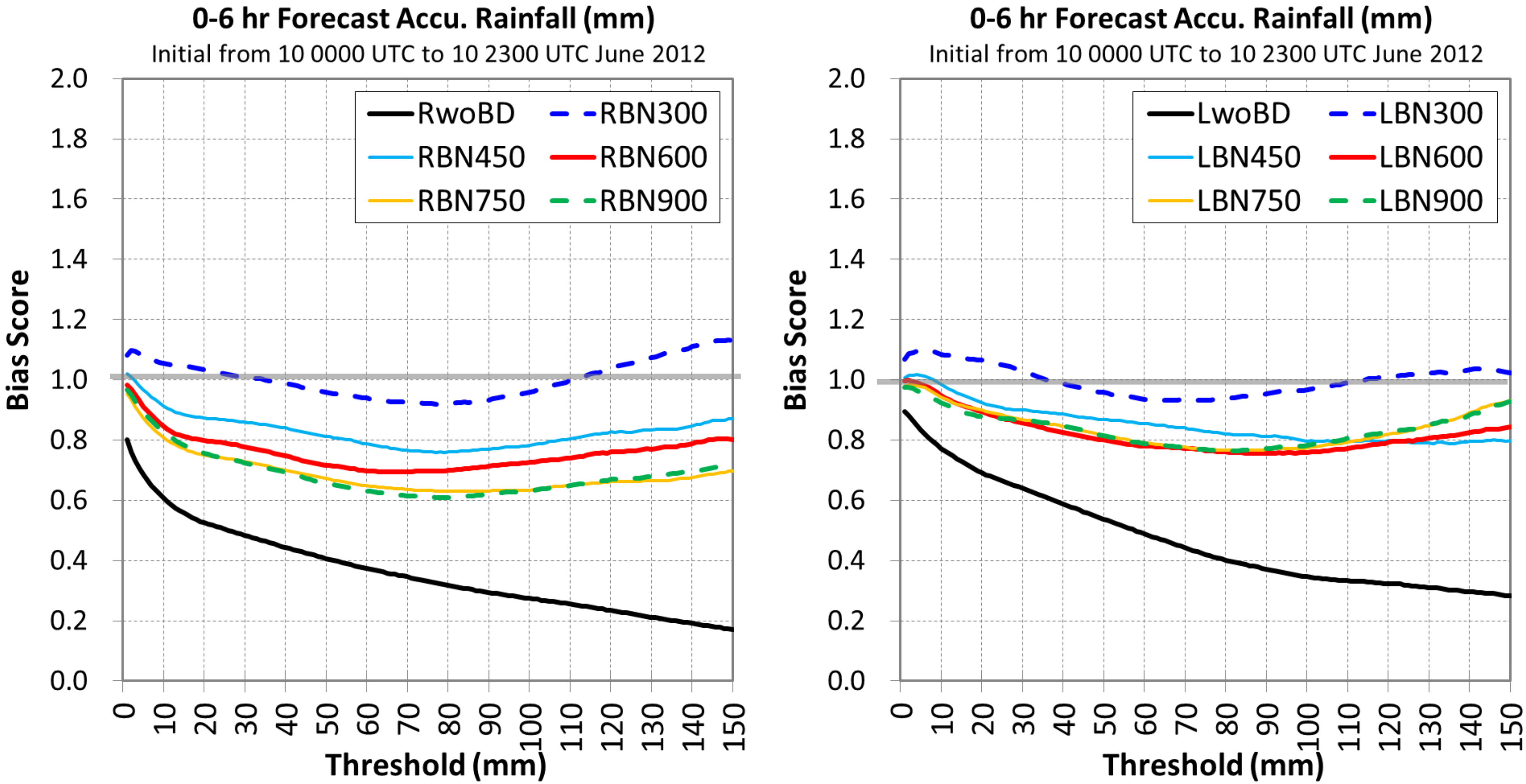


NCEPa
RwoBD
RBN300
RBN450
RBN600
RBN750
RBN900
Without Blending, the analysis is away from NCEP GFS
Moisture Flux Convergence(g/kg*1/s)
9
8
7
6
5
4
3
2
1
0
-1
-2
NCEPa
LwoBD
LBN300
LBN450
LBN600
LBN750
LBN900
Moisture Flux Convergence(g/kg*1/s)
9
8
7
6
5
4
3
2
1
0
-1
-2
0912
0918
1000
1006
1012
1018
Analysis Time (DDHH UTC)



- Improvement of RWRF is more significant than LETKF, and finally comparable between the two
- Empirically, CLS=600 km is the best


0-6 hr Forecast Accu. Rainfall (mm)
Initial from 10 0000 UTC to 10 2300 UTC June 2012
Extremal Dependence Index (EDI)
Threshold (mm)
RwoBD
RBN300
RBN450
RBN600
RBN750
RBN900
0-6 hr Forecast Accu. Rainfall (mm)
Initial from 10 0000 UTC to 10 2300 UTC June 2012
Extremal Dependence Index (EDI)
Threshold (mm)
LwoBD
LBN300
LBN450
LBN600
LBN750
LBN900



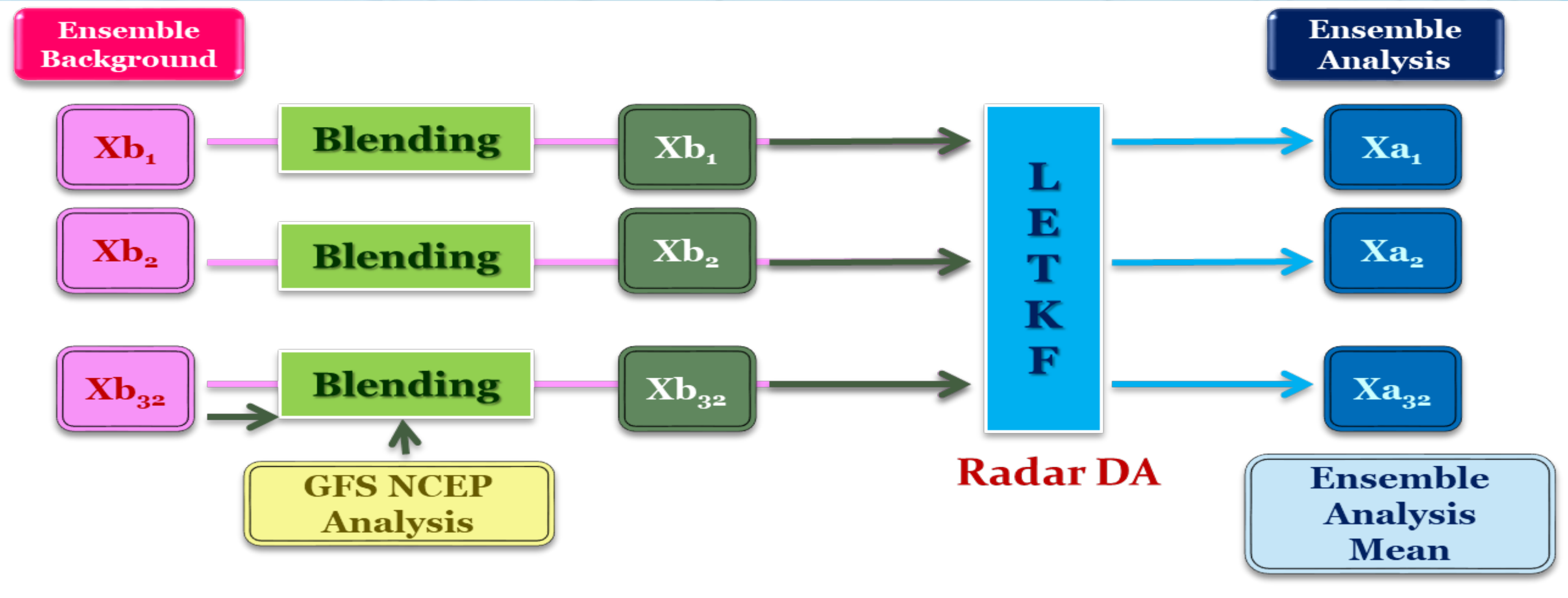
0-6 hr Forecast Accu. Rainfall (mm)
Initial from 10 0000 UTC to 10 2300 UTC June 2012
Bias Score
Threshold (mm)
RwoBD
RBN300
RBN450
RBN600
RBN750
RBN900
0-6 hr Forecast Accu. Rainfall (mm)
Initial from 10 0000 UTC to 10 2300 UTC June 2012
Bias Score
Threshold (mm)
LwoBD
LBN300
LBN450
LBN600
LBN750
LBN900

Summary

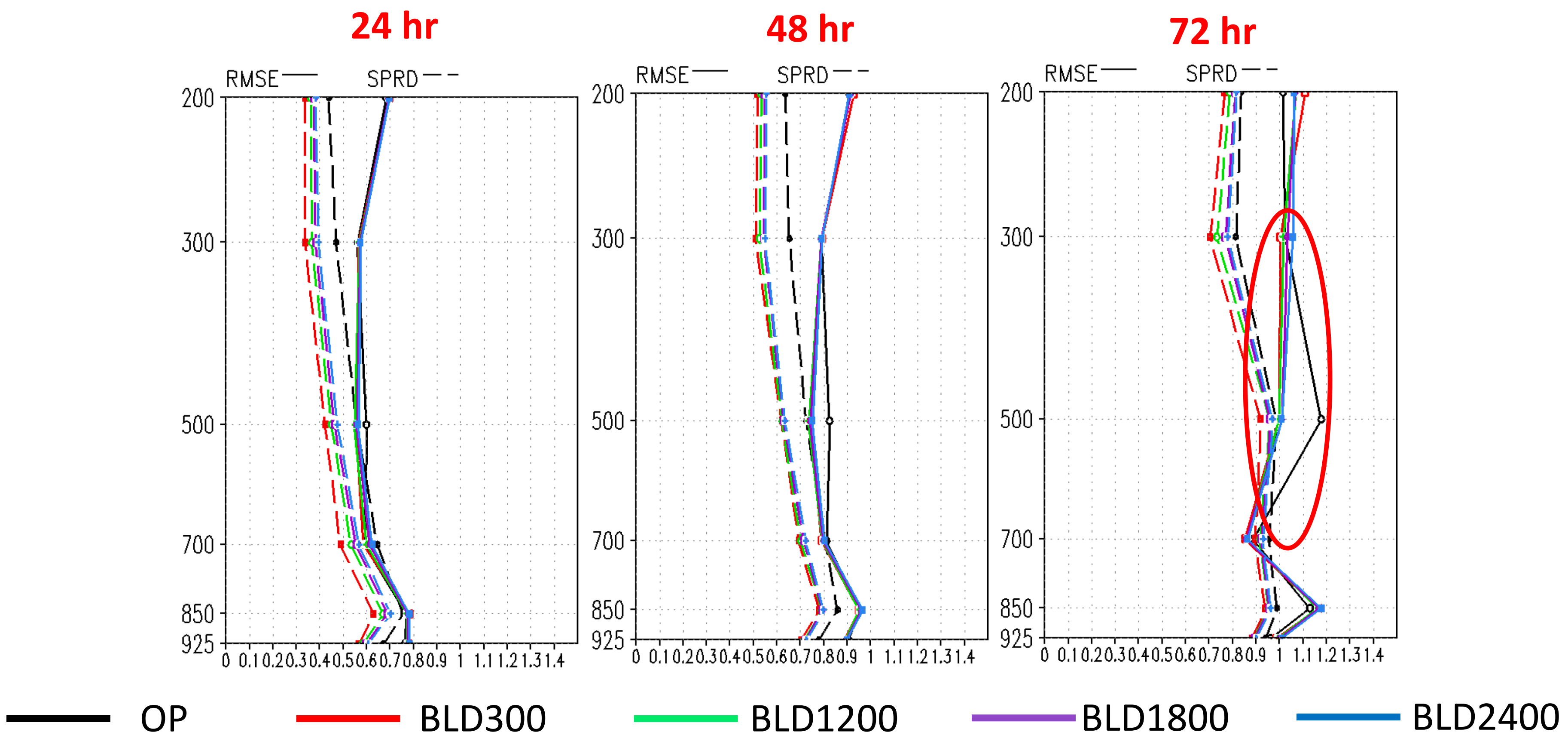
- The blending scheme is workable to remove the accumulated bias from the continuous cyclic DA
  - Both in 3DVAR and LETKF
- Blending the global wind and moisture variables have to the most contribution to improve the large scale bias
- The impact of the blending scheme has the consistent trend with the CLS (Cut off length scale), empirically, 600 km has the best performance
- The robustness of applying the blending scheme on convective scale should be further examined
- The CLS should be vertical dependent
  - Levels below 3-km may trust convective scale more

Undergoing

- Re-center procedure may introduce the imbalance: $\bar{X} + X' \rightarrow \bar{Y} + X'$
  - In particular for convective scale
  - Apply the blending scheme to each ensemble member, have to exam the impact on the spread



RMSE & SPRD



EPS driven by the full cyclic EAKF initial perturbation
Improve the accuracy, decrease the spread

Thank you