Latest Developments of WRF 4D-Var

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NCAR is sponsored by the National Science Foundation

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Sample Tangent Linear and Adjoint Check of WRFPLUS

Tangent linear check:6 hours

```
alpha_m=.1000E+00  coef=   0.98186174930325E+00  val_n= 0.3725210E+11  val_l= 0.3794027E+11
alpha_m=.1000E-01  coef=   0.99807498026522E+00  val_n= 0.3786723E+09  val_l= 0.3794027E+09
alpha_m=.1000E-02  coef=   0.99970559707666E+00  val_n= 0.3792910E+07  val_l= 0.3794027E+07
alpha_m=.1000E-03  coef=   0.99992019503144E+00  val_n= 0.3793724E+05  val_l= 0.3794027E+05
alpha_m=.1000E-04  coef=   0.10000447262220E+01  val_n= 0.3794196E+03  val_l= 0.3794027E+03
alpha_m=.1000E-05  coef=   0.99999981575068E+00  val_n= 0.3794026E+01  val_l= 0.3794027E+01
alpha_m=.1000E-06  coef=   0.99999998152933E+00  val_n= 0.3794027E-01  val_l= 0.3794027E-01
alpha_m=.1000E-07  coef=   0.99999990980017E+00  val_n= 0.3794026E-03  val_l= 0.3794027E-03
alpha_m=.1000E-08  coef=   0.99999956711797E+00  val_n= 0.3794025E-05  val_l= 0.3794027E-05
alpha_m=.1000E-09  coef=   0.10000030220656E+01  val_n= 0.3794038E-07  val_l= 0.3794027E-07
alpha_m=.1000E-10  coef=   0.99996176999678E+00  val_n= 0.3793882E-09  val_l= 0.3794027E-09
```

Adjoint check: 6 hours

```
ad_check: VAL_TL:     0.42476489986911E+11
ad_check: VAL_AD:     0.42476489986912E+11
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Lateral boundary condition control

$$J = J_b + J_o + J_c + J_{lbc}$$

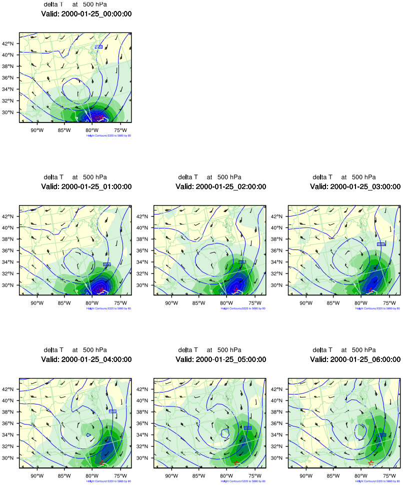
$$\begin{aligned} J_{lbc} &= \frac{1}{2}(\mathbf{x}(t_k) - \mathbf{x}_b(t_k))^T \mathbf{B}^{-1} (\mathbf{x}(t_k) - \mathbf{x}_b(t_k)) \\ &= \frac{1}{2}\delta\mathbf{x}(t_k)^T \mathbf{B}^{-1} \delta\mathbf{x}(t_k) \end{aligned}$$

J_{lbc} is the J_b at the end of the assimilation window and the lateral boundary control is obtained through

$$\frac{\partial \delta \mathbf{x}_{lbc}}{\partial t} = \frac{\delta\mathbf{x}(t_k) - \delta\mathbf{x}(t_0)}{t_k - t_0}$$

Single observation experiment

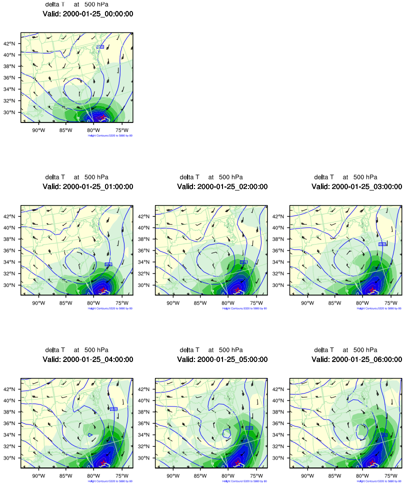
To investigate the impact of lateral boundary control, the 6h observation is placed close to boundary and downstream of the boundary inflow, we expect that the major analysis increments at 0h should be in boundary condition and outside of domain.



Remarks

Forecasted 500mb T difference (DA forecast - reference forecast)

- ⋆ is the location of obs. at the ending time (6h).
- LBC control is turned off



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- $O - B = -0.95K$
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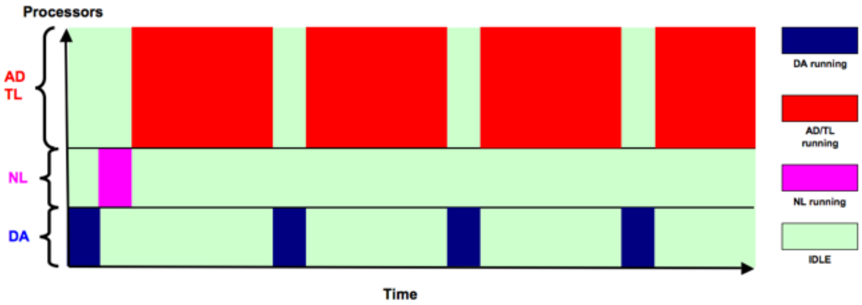
What we learn:

- The major increment is in the boundary condition(south boundary, invisible here)
- There is almost no increment in initial condition.
- For observations close to in-flow boundary, the impact of LBC control is important.

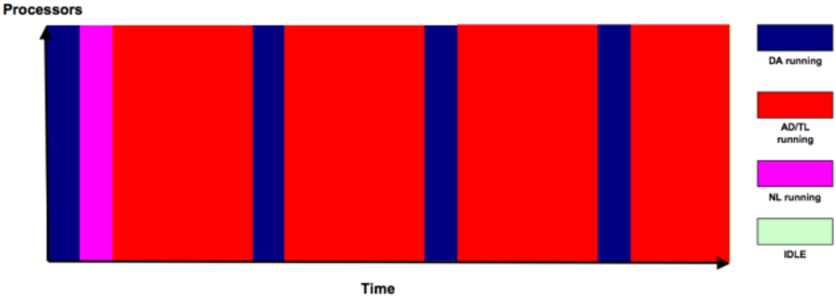
WRF 4D-Var V3.2: Parallel run using part of processors

4D-Var is a sequential algorithm. However, the old WRF 4D-Var constructed on the Multiple Program Multiple Data mode, which have to split the total processors into 3 subsets for DA, NL and AD/TL. Lots of CPU time are wasted



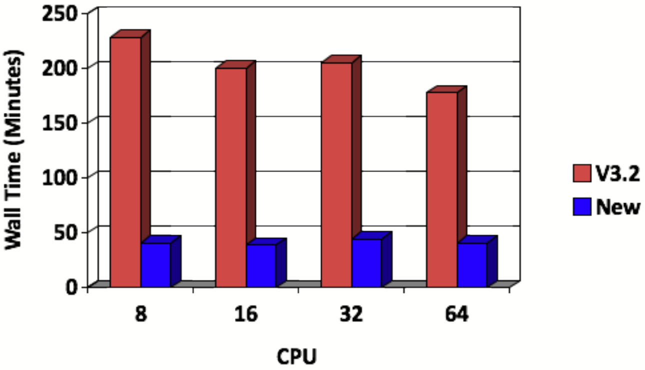
WRF 4D-Var V3.3.1: Parallel run using all processors

Benefit from the single executable framework, every CPU is working at any time. No IDLE any more.



Performance improvement WRF 4D-Var framework

- $270x180x41@20km$,6h window, 1h obs_bin, 10 iterations
- 10 iterations FGAT (identity TL/AD model), NCAR bluefire (IBM P6)



Parallel Strategies for WRFPLUS

- Modify registry tools and add the capability to generate tangent linear and adjoint codes for halo exchanges.
- Add halo_nta identifier in registry entry to instruct registry to automatically generate tangent linear and adjoint code for some halo exchange stencils.

Parallel timing/speedup of WRF NLM/TLM/ADM

Domain size: 350x250x57L, 27km
On IBM bluefire, xlf V13.01, per time step

Processors	Perfect	NLM	TLM	ADM
8	1	4.06s/1.0	8.14s/1.0	22.06s/1.0
16	2	2.14s/1.90	4.27s/1.91	11.37s/1.94
32	4	1.09s/3.72	2.17s/3.75	5.89s/3.74
64	8	0.63s/6.44	1.21s/6.73	3.25s/6.79
128	16	0.32s/12.69	0.62s/13.13	1.75s/12.61
256	32	0.32s/12.69	0.44s/18.50	1.28s/17.23

Parallel timing/speedup of WRF NLM/TLM/ADM

Domain size: 700x500x41L, 15km
On IBM bluefire, xlf V13.01, per time step

Processors	Perfect	NLM	TLM	ADM
64	1	1.57s/1.0	3.22s/1.0	7.69s/1.0
128	2	0.82s/1.91	1.61s/2.0	4.27s/1.80
256	4	0.71s/2.21	1.30s/2.48	3.95s/1.94
512	8	0.39s/4.03	0.61s/5.28	1.83s/4.20
1024	16	0.24s/6.54	0.34s/9.47	0.91s/8.45

Radar radial wind data assimilation

- TRUTH —— Initial condition from TRUTH (13-h forecast initialized at 2002061212Z from AWIPS 3-h analysis) run cutted by ndown, boundary condition from NCEP GFS data.
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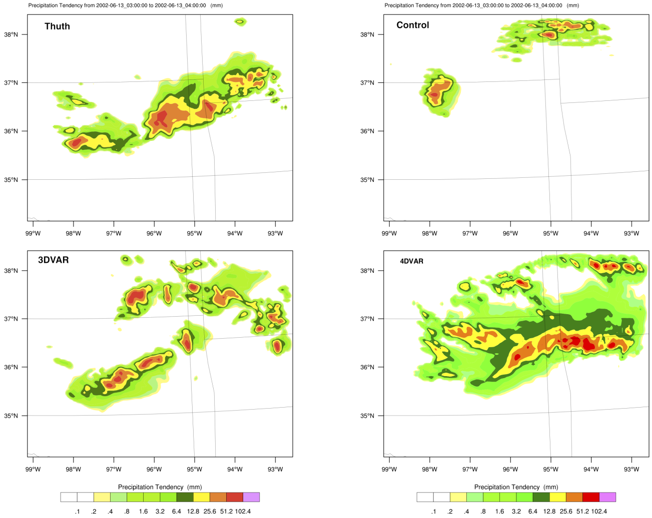
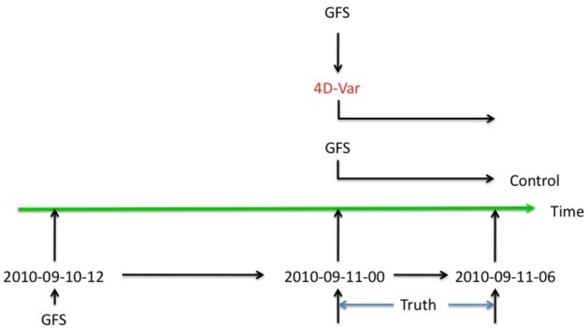
OSSE 3rd hour precipitation simulation



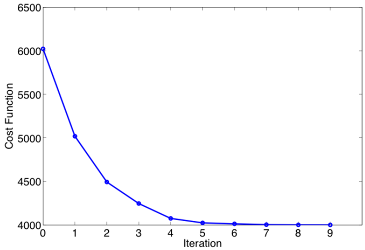
Precipitation assimilation

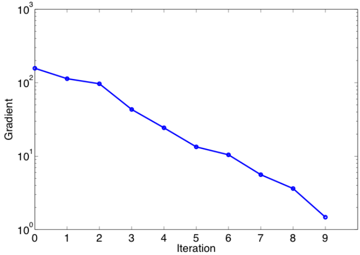
- WRFPLUS includes the TL and AD of:
  - Large scale condensation (mp_physics=98)
  - CUDU cumulus scheme (cu_physics=98)
- An OSSE experiment are conducted to verify the capability
- 2010-09-11-00 +6h precipitation (IC and BC come from +12h forecast from 2010-09-10-12 NCEP FNL)

OSSE exp. flowchart

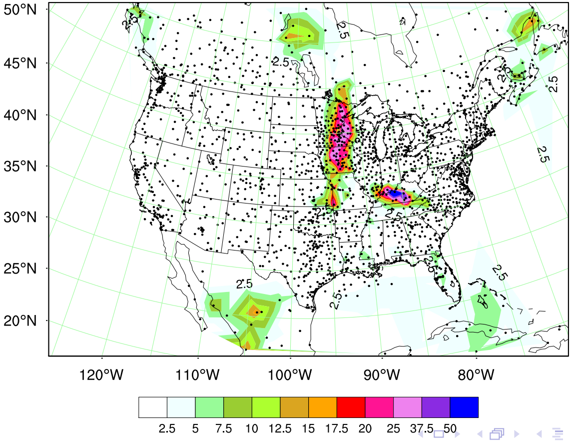


Minimization

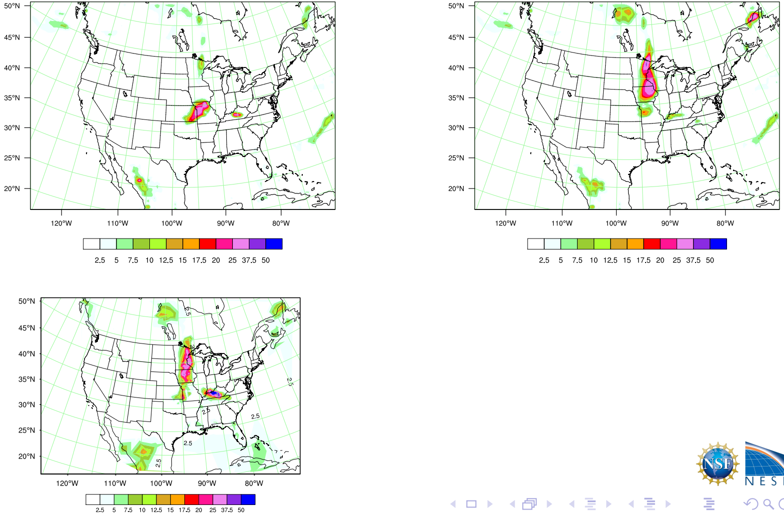




2010091100 +6h simulated accumulated precipitation forecast, sampled by 2066 metar station+random error



+6h total precipitation simulations



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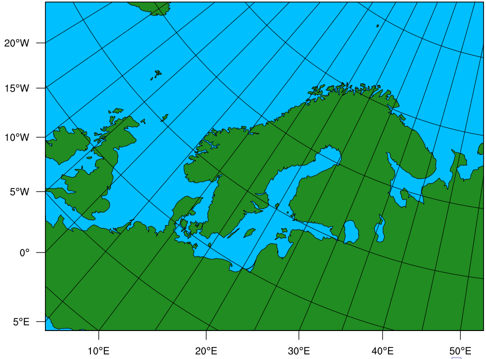
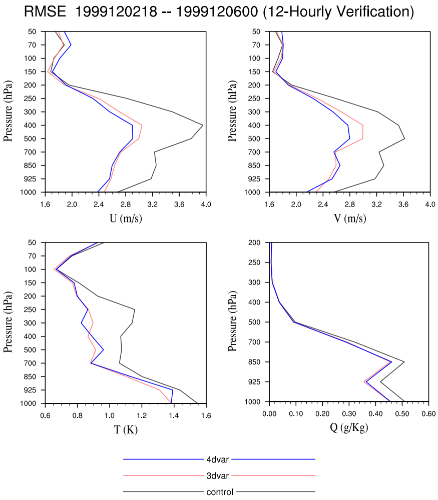
1999 Denmark Storm

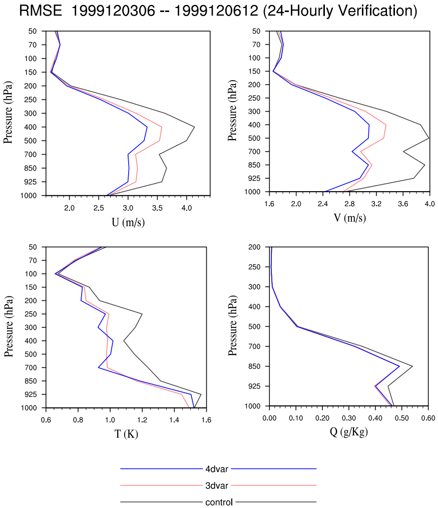
- Grids: 120x90x45L
- Resolution: 30km
- Period: 1999120100-1999120512 @0Z,6Z,12Z,18Z
- Prepbufr conventional observational data
- Start from NCEP FNL, full cycle run
- 48h forecasts from FG (control), 3dvar, 4dvar and 4dvar_lbc (4dvar with LBC control)
- Verified against ECMWF re-analysis



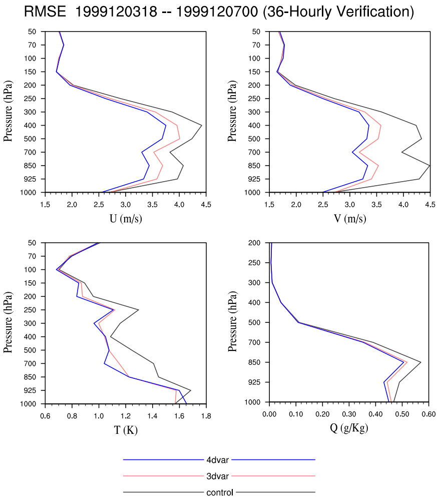
Averaged RMSE of 12H forecast verification



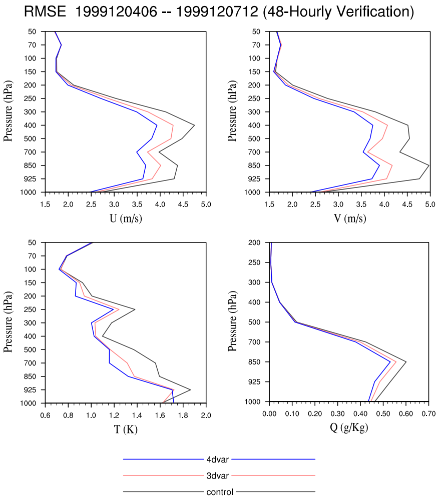
Averaged RMSE of 24H forecast verification



Averaged RMSE of 36H forecast verification

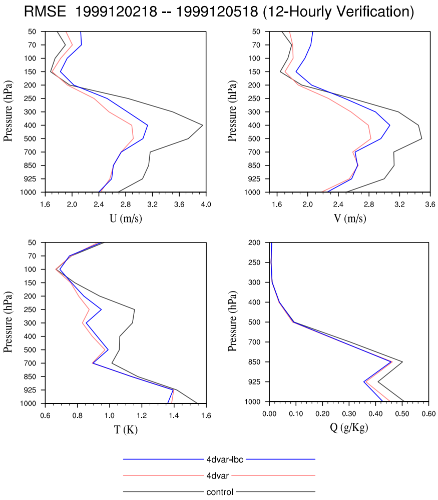


Averaged RMSE of 48H forecast verification



Comparison of the Exp. of 4D-Var and Exp. 4D-Var with LBC control

Averaged RMSE of 12H forecast verification



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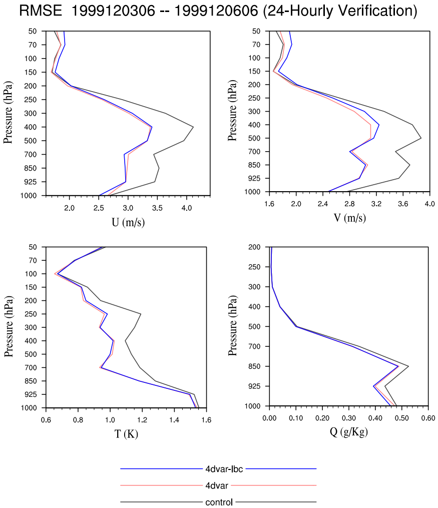

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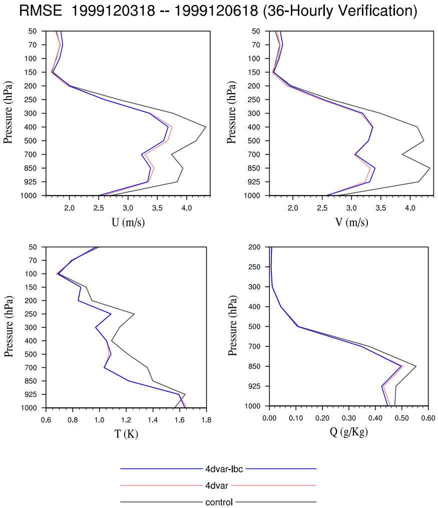

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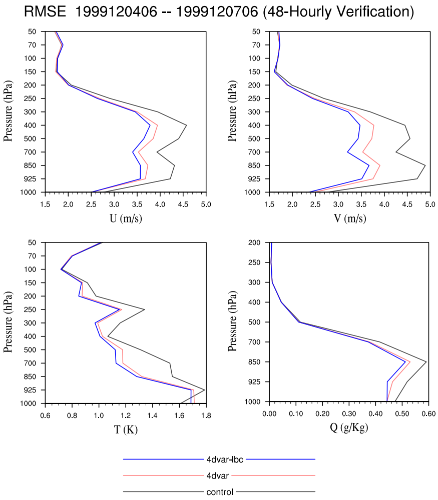

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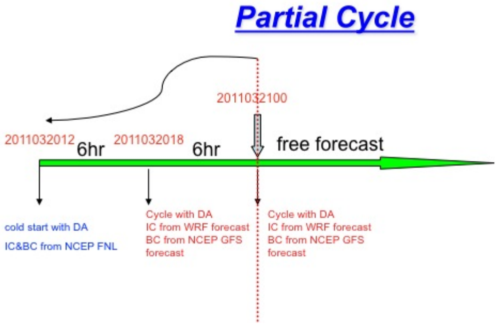
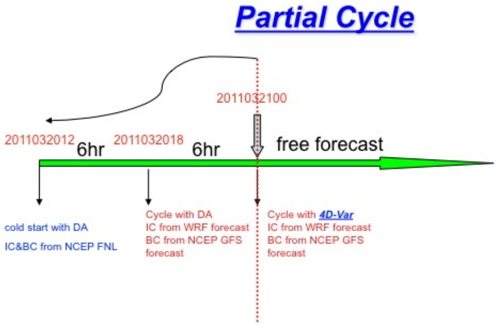
CWB OP23 Partial Cycle

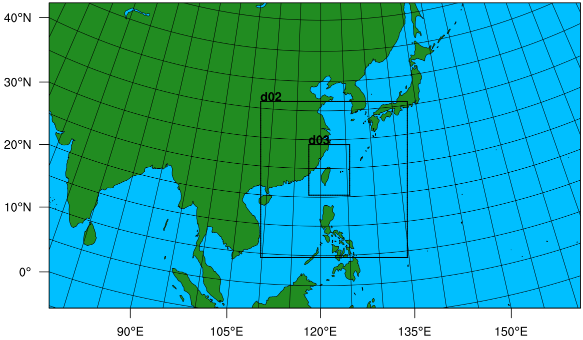


CWB OP23 Partial Cycle 4D-Var Ver. 0

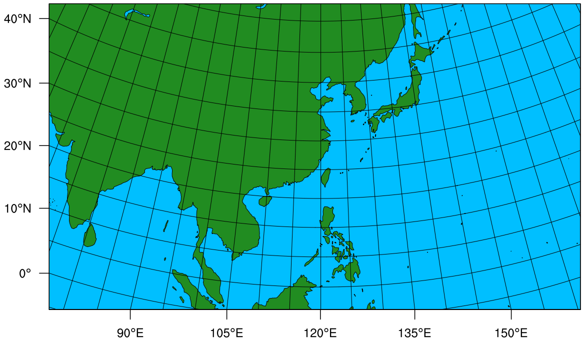


- Using 0-6h observations in 3^{rd} DTG
- no DFI initialization in 3^{rd} DTG

CWB OP23 Domains

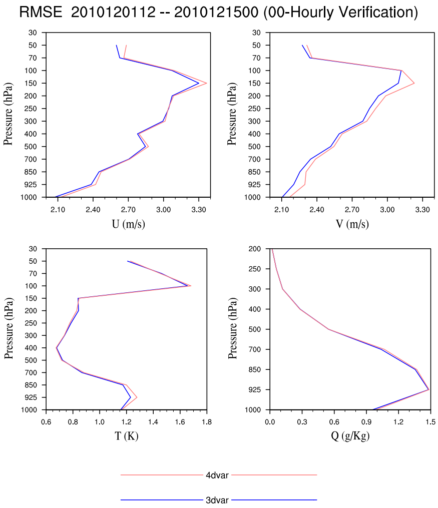


CWB OP23 4D-Var Ver. 0 Domain

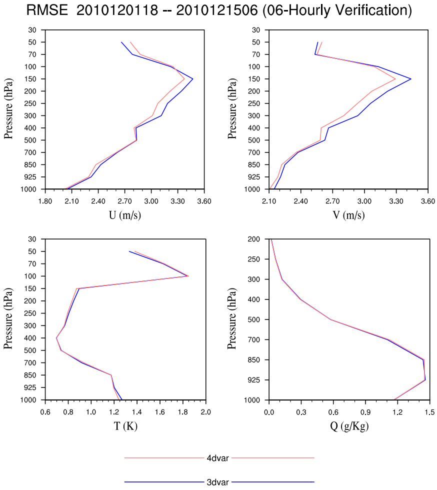


- Analysis/forecast times: 00 and 12UTC of 2010-12-01—12-15
- 0-48h forecast verified against ECMWF reanalysis

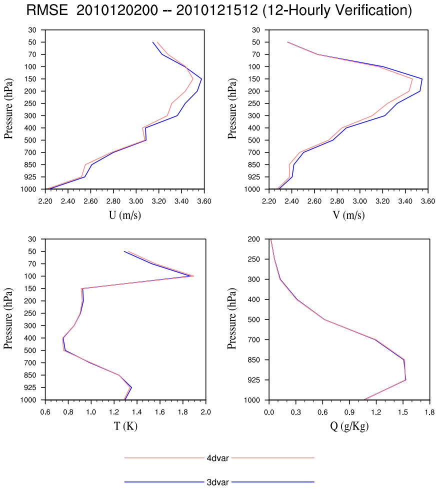
CWB OP23 4D-Var Ver. 0 Verification 00h



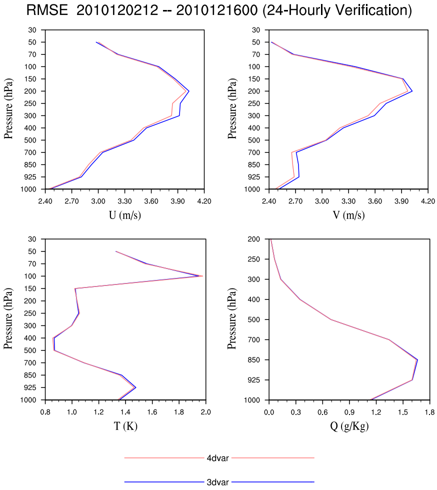
CWB OP23 4D-Var Ver. 0 Verification 06h



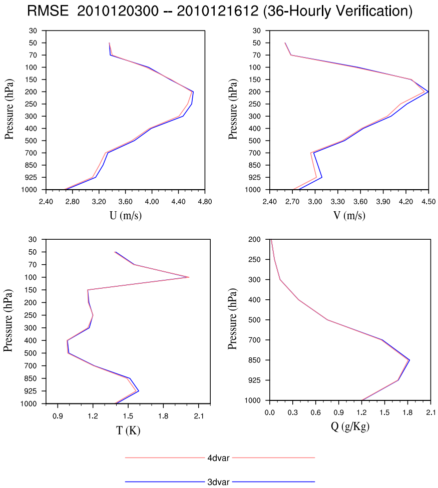
CWB OP23 4D-Var Ver. 0 Verification 12h



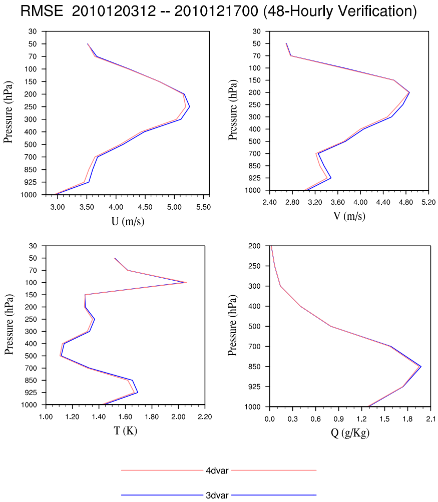
CWB OP23 4D-Var Ver. 0 Verification 24h



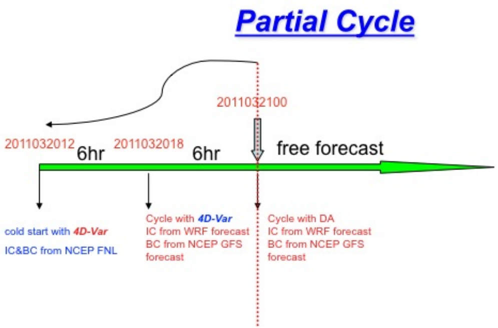
CWB OP23 4D-Var Ver. 0 Verification 36h



CWB OP23 4D-Var Ver. 0 Verification 48h



Proposed CWB OP23 Partial Cycle 4D-Var Ver. 1



- Using 4D-Var in 1^{st} and 2^{nd} DTGs, no cut-off time.
- Using 3D-Var in 3^{rd} DTG.
- Using time window from 0–6h, fully takes advantage of the observations.

Parallel timing/speedup of CWB OP23 on NCAR bluefire

Domain size: 222x128x45L, 45km
On IBM bluefire, xlf V13.01, cost of 5 iterations (40 iteration to converge)

Processors	Perfect	Total
32	1	97m/1.0
64	2	43m/2.26
128	4	26m/3.73
256	8	19m/5.1

Summary

- The single executable WRF 4D-Var system was developed and has showed promising performance.
- The new WRF 4D-Var system has the capability to assimilate conventional observational data (little_r or prepbufr format),radiance in bufr format and radar data.

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Thank You

The NESL Mission is:
To advance understanding of weather, climate, atmospheric composition and processes;
To provide facility support to the wider community; and,
To apply the results to benefit society.

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