Recent upgrades and improvements of WRF 4D-Var V3.3

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NCAR Earth System Laboratory

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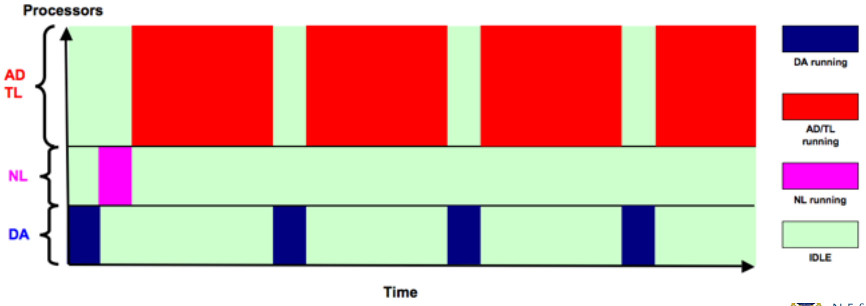
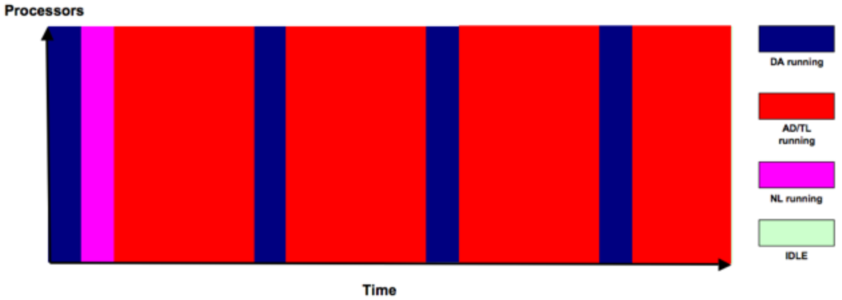
WRF 4D-Var V3.2: Parallel run using part of processors

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



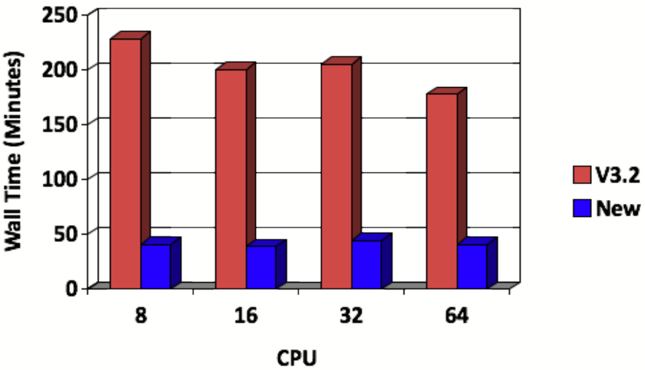
WRF 4D-Var V3.3: Parallel run using all processors

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



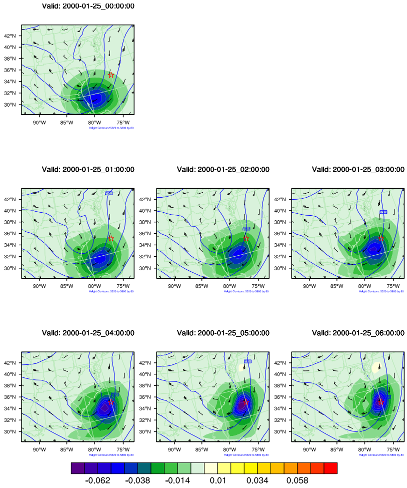
Performance improvement WRF 4D-Var framework

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



Single observation experiment I

- Initial time: 2000_01_25_00 : 00 : 00
- Ending time: 2000_01_25_06 : 00 : 00
- Observation: 500 mb temperature at ending time
  $O - B = -1.168K$
- Plotting the difference at ending time between the forecast from analysis and from background to investigate the impact of 6h obs. on IC.



Remarks

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

- ⋆ is the location of obs. at the ending time (6h).
- Initial perturbation is on the upstream of the obs.
- Evolved perturbation at 6h hit the obs. location

What we learn:

- WRF 4D-Var has the capability to assimilate the observations within a time window.
- WRF 4D-Var produces the flow-dependent analysis increments.

Consider Lateral boundary condition as control variable

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

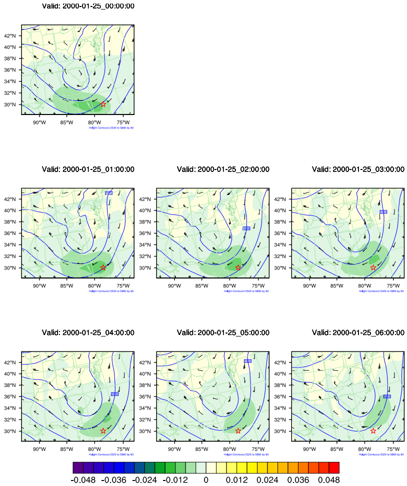
$$\begin{aligned} J_{lbc} &= \frac{1}{2}(\mathbf{x}(t_k) - \mathbf{x}_b(t_k))^T \mathbf{B}^{-1} (\mathbf{x}(t_k) - \mathbf{x}_b(t_k)) \\ &= \frac{1}{2}\delta\mathbf{x}(t_k)^T \mathbf{B}^{-1} \delta\mathbf{x}(t_k) \end{aligned}$$

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 II

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

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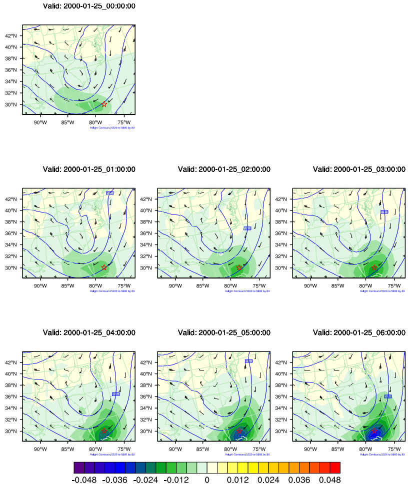
- LBC control is turned off



Remarks

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

- ⋆ is the location of obs. at the ending time (6h).
- $O - B = -0.95K$
- LBC control is turned on

What we learn:

- The major increment is in the boundary condition(south boundary, invisible here)
- Increment in initial condition alone is hard to fit the observation.
- For observations close to in-flow boundary, the impact of LBC control is important.

An OSSE radar data assimilation with WRF 4D-Var

- 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.
- NODA —— Both initial condition and boundary condition from NCEP GFS data.

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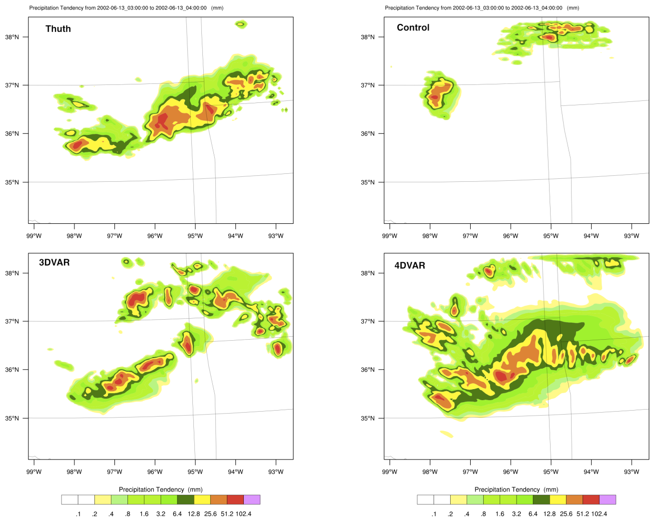
OSSE 3rd hour precipitation simulation



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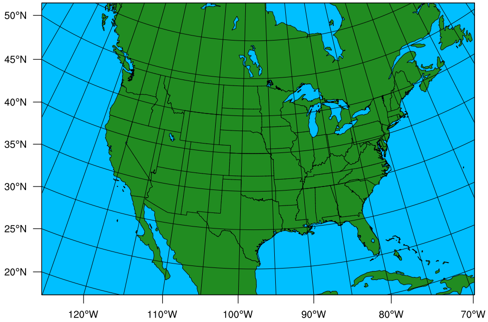
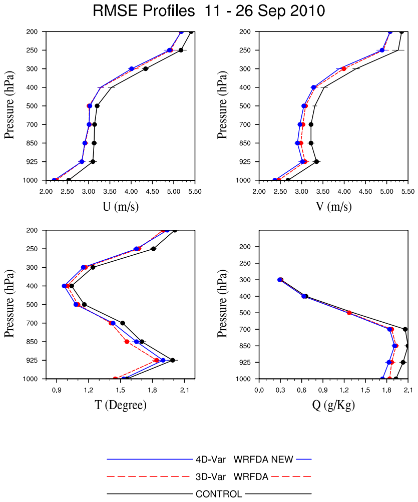
Experiment configration

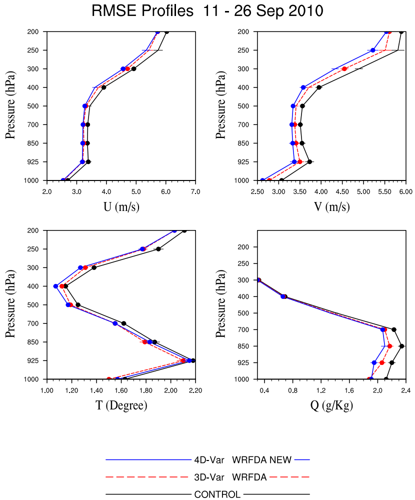
- Grids: 105x72x28L
- Resolution: 60km
- Period: 2010091100-2010092600 @0Z,6Z,12Z,18Z
- First guess is the 12h forecast from NCEP FNL
- 48h forecasts from FG (control), 3DVAR and 4DVAR
- Verified against NCEP GDAS prepbufr data



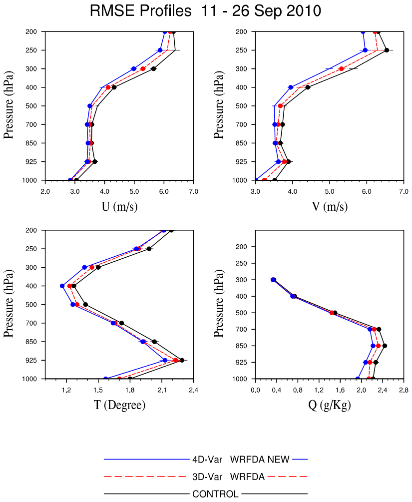
Averaged RMSE of 24H forecast verification



Averaged RMSE of 36H forecast verification



Averaged RMSE of 48H forecast verification



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Upcoming

A hand-on tutorial for WRF 4D-Var V3.3 will be presented on June 24, Friday morning 8:30AM-10:00AM

- Overview
- Installation
- Setup
- Run

Thank You

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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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