Recent upgrades and improvements of WRF 4D-Var system

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- Multiple Program Multiple Data (MPMD) framework, needs 3 executables: WRFDA, WRFNL and WRFPLUS.
- Simplified physical packages: surface drag, large scale condensation and a cumulus parameterization schemes (Q. Xiao).
- Weak constraint with digital filter.

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- Hard to do a complete adjoint check due to initial design of framework.

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- Capability to do tangent linear and adjoint test over any length of time window.
- New WRFPLUS can be used as a standalone tool or as a component in 4D-Var system.

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
```

Single executable 4D-Var

WRFPLUS includes WRF NL, AD and TL model and they are used as a subroutine in WRF 4D-Var, other than being called via shell scripts.

Nonlinear call

old	call da_system ("da_run_wrf_nl.ksh")
new	call da_nl_model

Tangent linear call

old	call da_system ("da_run_wrfplus_tl.ksh")
new	call da_tl_model

Adjoint call

old	call da_system ("da_run_wrfplus_ad.ksh")
new	call da_ad_model

Memory exchange

The information (TL perturbation, adjoint forcing, basic states and gradient) is exchanged via linked lists.

Read basic states

```
call domain_clock_get( grid, current_timestr=timestr )
call da_read_basicstates ( xbx, grid, ... )
```

Save TL perturbation

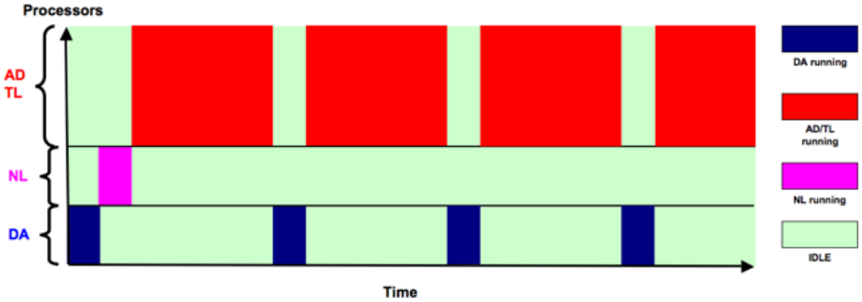
```
call push_tl_pert (timestr)
```

Save AD forcing

```
call push_ad_forcing (timestr)
```

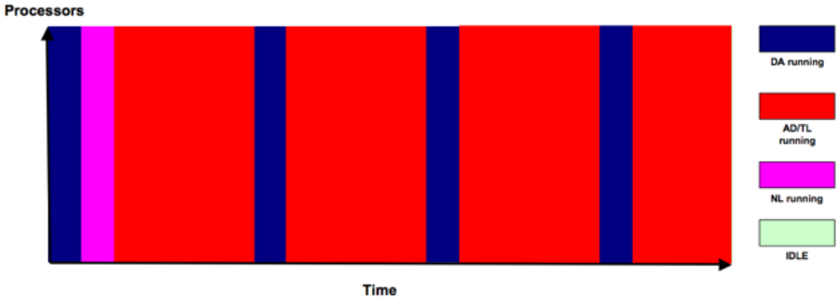
Parallel run using all processors

4D-Var is a sequential algorithm. However, the current parallel 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



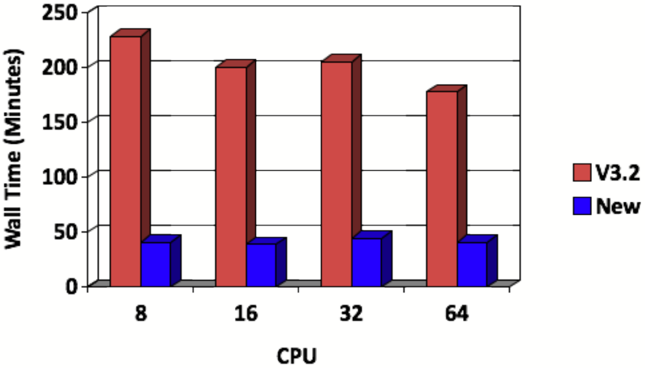
Parallel run using all processors

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



Performance improvement WRF 4DVar framework only

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



Consider Lateral boundary condition as control variable

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

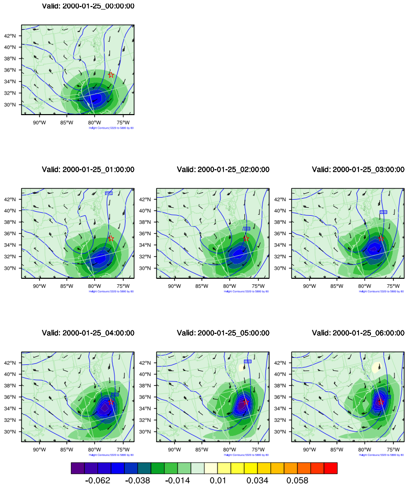
$$\begin{aligned} J_{lbc} &= \frac{1}{2}(\mathbf{x}(t_k) - \mathbf{x}_b(t_k))^T \mathbf{B}^{-1} (\mathbf{x}(t_k) - \mathbf{x}_b(t_k)) \\ &= \frac{1}{2}\delta\mathbf{x}(t_k)^T \mathbf{B}^{-1} \delta\mathbf{x}(t_k) \end{aligned}$$

J_{lbc} is the J_b at the end of the assimilation window
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 experiments

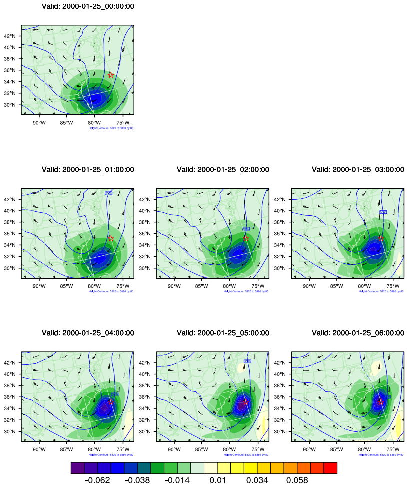
- Initial time: 2000_01_25_00 : 00 : 00
- Ending time: 2000_01_25_06 : 00 : 00
- Observation: 500 mb Temperature at ending time
  $O - B = -1.168K$
- To investigate the difference at ending time between the forecast from analysis and from background.



Remarks

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

- $\star$ is the location of obs. at the ending time (6h).
- JcDF is turned on
- LBC control is turned on
- Initial perturbation is on the upstream of the obs.
- Evolved perturbation at 6h hit the obs. location



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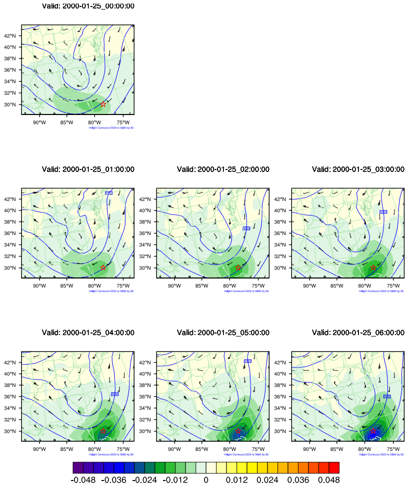
Additional experiments design
Observation close to boundary

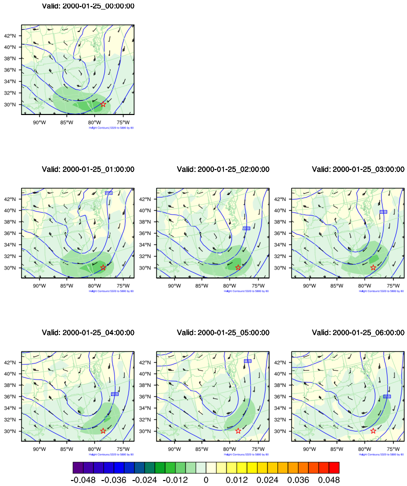
To investigate the impact of including boundary condition in data assimilation, the 6h observation is close to boundary and downstream of the boundary, we expect that the analysis response at 0h should be in boundary condition other than initial condition.



Remarks

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

- ⋆ is the location of obs. at the ending time (6h).
- JcDF is turned on
- $O - B = -0.95K$
- LBC control is turned on
- Main initial perturbation is in the boundary condition other than in the initial condition (south boundary, invisible here)
- Evolved perturbation is coming from boundary



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- Main Initial perturbation is in the location of the obs., it is fake
- Evolved perturbation at 6h is moving out from the obs. location

An OSSE radar data assimilation with WRF 4D-Var

(Yongrun Guo and Jenny Sun)

- 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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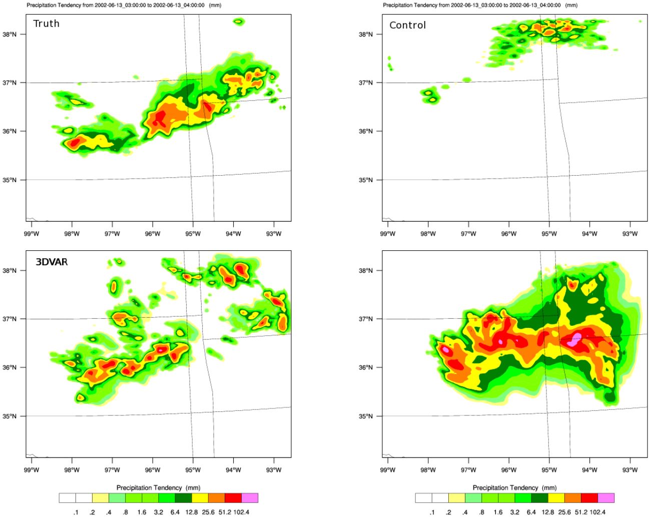
- 4DVAR —— 4DVAR analysis at 2002061301Z used as initial condition, and boundary condition from NCEP GFS. The radar radial velocity at 4 times: 200206130100, 05, 10, and 15, are assimilated (total data points =

OSSE 3rd hour precipitation simulation



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- However, the coverage and intensity of the precipitation are more than the observation.
- Possible reason: The new WRFPLUS is a dynamic-only model, PBL and microphysics are needed.

Summary

- The single executable WRF 4DVar system was developed and has showed promising performance.
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- The new WRF 4DVar system is able to consider lateral boundary condition as control variable and digital filter can be used as a weak constraint to suppress the high frequency noise.

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- Parallelization of WRF tangent linear code has been done. We are working on the parallelization of WRF adjoint codes.

Thank You

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To provide facility support to the wider community; and,
To apply the results to benefit society.

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