WRF 4D-Var

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WRFDA Tutorial

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- 4D-Var combines observations at different times during the 4D-Var window in a way that reduces analysis error
- 4D-Var propagates information horizontally and vertically in a meteorologically more consistent way

Incremental 4D-Var formulation

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$$J_o = \frac{1}{2}\sum_{k=1}^{K}[(\overbrace{\mathbf{y}_k - H_k M_k \mathbf{x}_b}^{innovation} - \mathbf{H}_k\mathbf{M}_k\delta\mathbf{x})^T\mathbf{R}^{-1}$$

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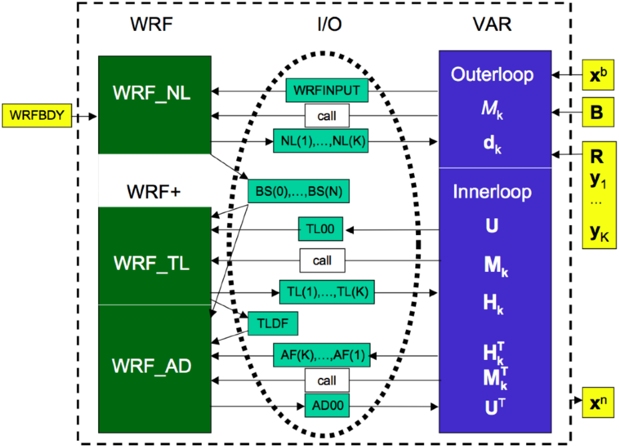
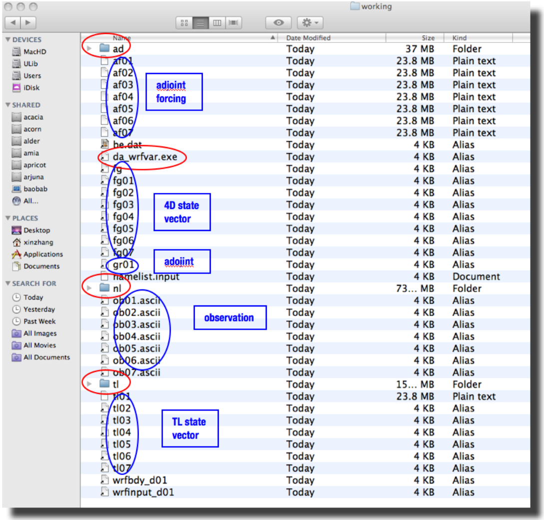
$\mathbf{M}_k$: tangent linear model and ${\mathbf{M}_k}^T$: adjoint model are needed

Structure of WRF 4D-Var



Structure of WRF 4D-Var (Cont'd)



Observations used by 4D-Var

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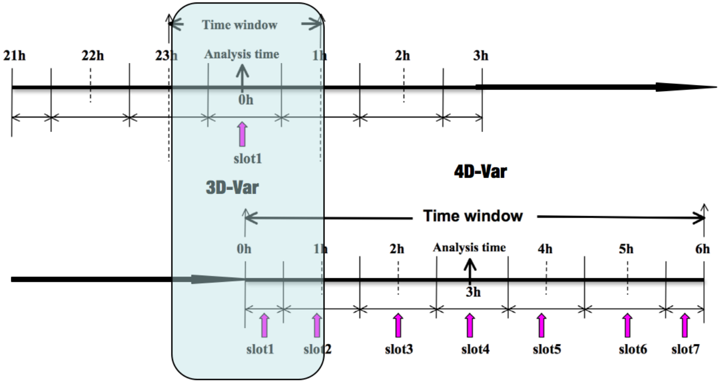

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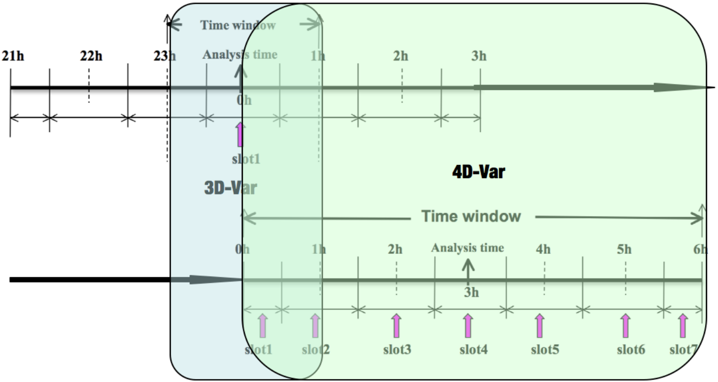

Weak constraint with digital filter

$$J = J_b + J_o + J_c$$

$$J_b(\mathbf{x}_0) = \frac{1}{2}\left[(\mathbf{x}_0 - \mathbf{x}_b)^T \mathbf{B}^{-1}(\mathbf{x}_0 - \mathbf{x}_b)\right]$$

$$J_o(\mathbf{x}_0) = \frac{1}{2}\sum_{k=1}^{K}\left[(\mathbf{H}_k\mathbf{x}_k - \mathbf{y}_k)^T \mathbf{R}^{-1}(\mathbf{H}_k\mathbf{x}_k - \mathbf{y}_k)\right]$$

$$\begin{aligned} J_c(\mathbf{x}_0) &= \frac{\gamma_{df}}{2}\left[\left(\delta\mathbf{x}_{N/2} - \delta\mathbf{x}_{N/2}^{df}\right)^T \mathbf{C}^{-1}\left(\delta\mathbf{x}_{N/2} - \delta\mathbf{x}_{N/2}^{df}\right)\right] \\ &= \frac{\gamma_{df}}{2}\left[\left(\delta\mathbf{x}_{N/2} - \sum_{i=0}^{N} f_i\delta\mathbf{x}_i\right)^T \mathbf{C}^{-1}\left(\delta\mathbf{x}_{N/2} - \sum_{i=0}^{N} f_i\delta\mathbf{x}_i\right)\right] \\ &= \frac{\gamma_{df}}{2}\left[\left(\sum_{i=0}^{N} h_i\delta\mathbf{x}_i\right)^T \mathbf{C}^{-1}\left(\sum_{i=0}^{N} h_i\delta\mathbf{x}_i\right)\right] \end{aligned}$$

where:

$$h_i = \begin{cases} -f_i, & \text{if } i \neq N/2 \\ 1 - f_i, & \text{if } i = N/2 \end{cases}$$

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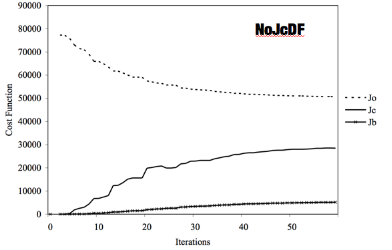
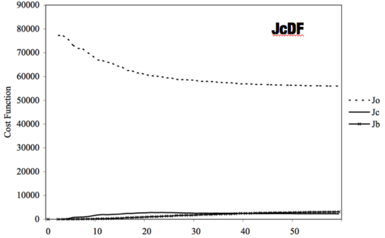
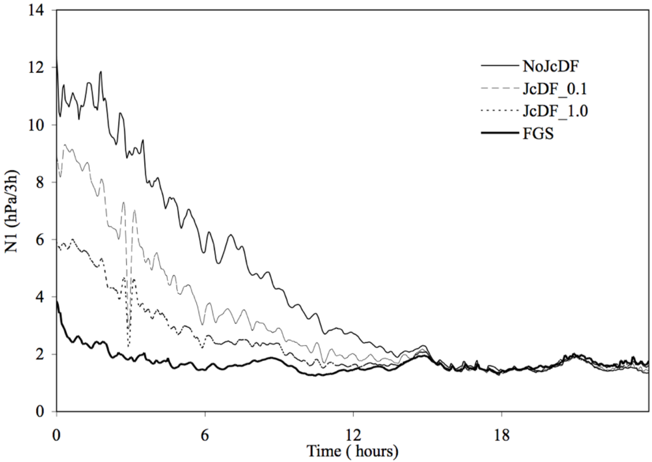




Weak constraint with digital filter (domain averaged surface pressure variation)



First 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.

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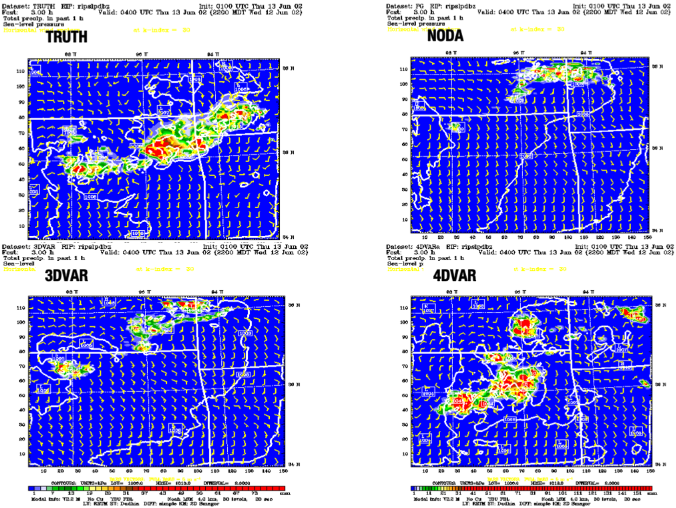
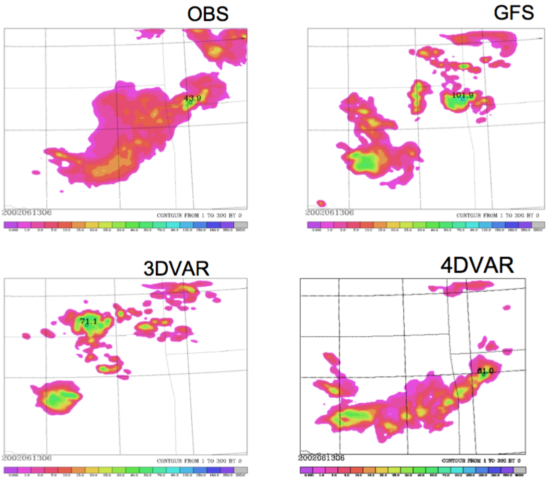
- 3DVAR —–3DVAR analysis at 2002061301Z used as the initial condition, and boundary condition from NCEP GFS. Only Radar radial velocity at 2002061301Z assimilated (total data points = 65,195).
- 4DVAR —– 4DVAR analysis at 2002061301Z used as initial condition, and boundary condition from NCEP GFS. The radar radial velocity at 4 times: 200206130100, 05, 10, and 15, are assimilated (total data points = 262,445).

OSSE 3h precipitation simulation



Real Data Experiment



Quick Start

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- Setup 4D-Var working directory
  - Reference directory : $WRFDA/var/test/4dvar$
  - See detail in Users' guide Chapter 6

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- On all platforms other than IBM, the calculated gradient might be wrong...

Single executable 4D-Var

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

Non-linear 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
```

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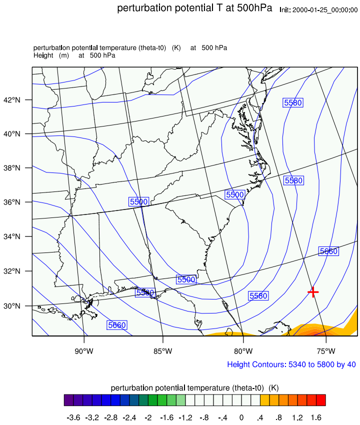

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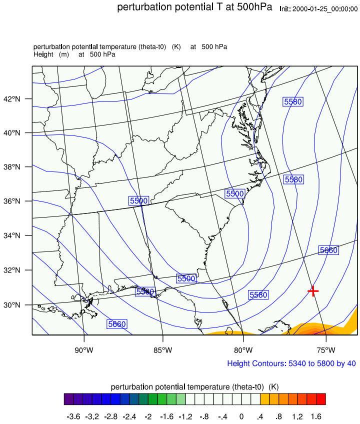
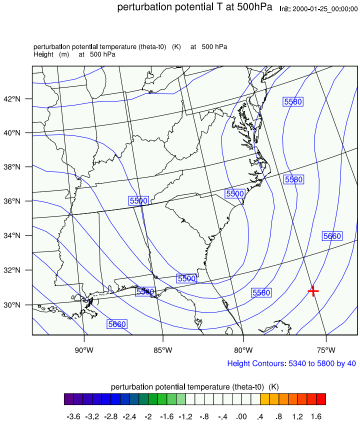
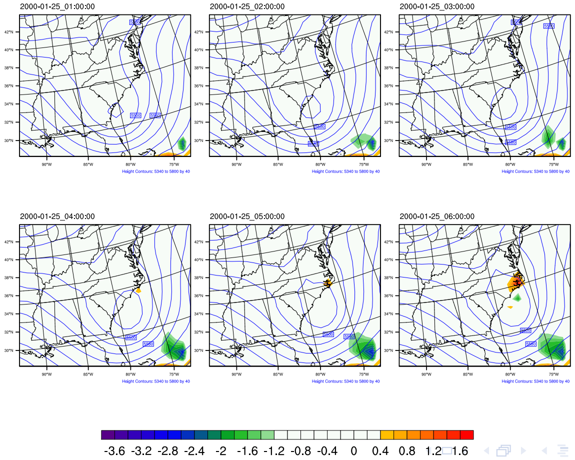




6h evolution w/o LBC control

perturbation potential T at 500 hPa (K)



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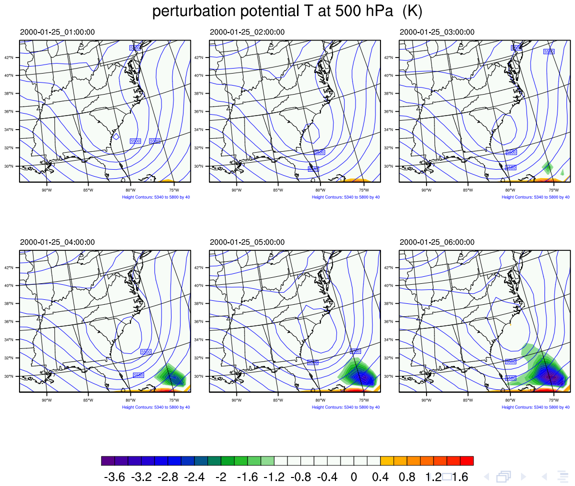

Thank You

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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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