

WRF 4D-Var

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WRFDA Tutorial

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4D-Var versus 3D-Var

(Adopted from ECMWF training Course 2008)

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- The dynamics and physics of the forecast model in an integral part of 4D-Var, so observations are used in a meteorologically more consistent way
- 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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$$J_o = \frac{1}{2} \sum_{k=1}^K \left[\overbrace{(\mathbf{y}_k - H_k M_k \mathbf{x}_b)}^{\text{innovation}} - \mathbf{H}_k \mathbf{M}_k \delta \mathbf{x} \right]^T \mathbf{R}^{-1} \left[\mathbf{y}_k - H_k M_k \mathbf{x}_b - \mathbf{H}_k \mathbf{M}_k \delta \mathbf{x} \right]$$

Incremental 4D-Var formulation (Cont'd)

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M_k : Model integration from step 0 to step k.

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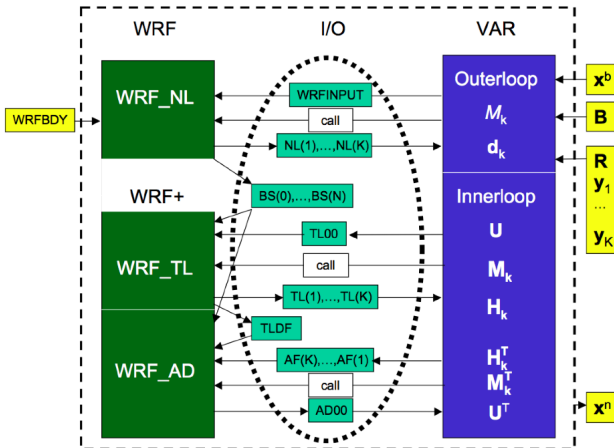
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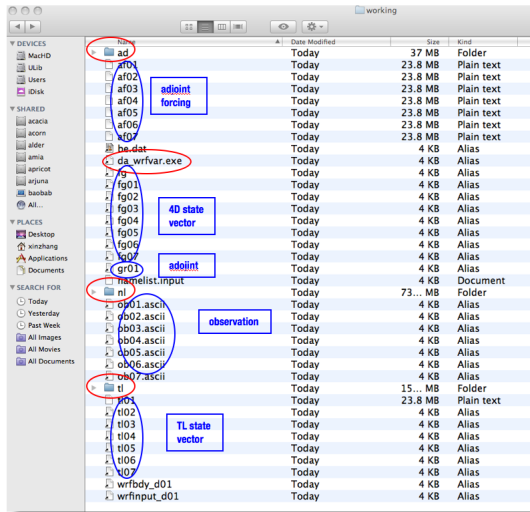
M_k : Model integration from step 0 to step k.

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

Structure of WRF 4D-Var



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



Name	Date Modified	Size	Kind
ad	Today	37 MB	Folder
af01	Today	23.8 MB	Plain text
af02	Today	23.8 MB	Plain text
af03	Today	23.8 MB	Plain text
af04	Today	23.8 MB	Plain text
af05	Today	23.8 MB	Plain text
af06	Today	23.8 MB	Plain text
af07	Today	23.8 MB	Plain text
be.dat	Today	4 KB	Alias
da_wrfvar.exe	Today	4 KB	Alias
fg	Today	4 KB	Alias
fg01	Today	4 KB	Alias
fg02	Today	4 KB	Alias
fg03	Today	4 KB	Alias
fg04	Today	4 KB	Alias
fg05	Today	4 KB	Alias
fg06	Today	4 KB	Alias
fg07	Today	4 KB	Alias
gr01	Today	4 KB	Alias
hamelist.input	Today	4 KB	Document
nl	Today	73... MB	Folder
ob01.asci	Today	4 KB	Alias
ob02.asci	Today	4 KB	Alias
ob03.asci	Today	4 KB	Alias
ob04.asci	Today	4 KB	Alias
ob05.asci	Today	4 KB	Alias
ob06.asci	Today	4 KB	Alias
ob07.asci	Today	4 KB	Alias
tl	Today	15... MB	Folder
tl01	Today	23.8 MB	Plain text
tl02	Today	4 KB	Alias
tl03	Today	4 KB	Alias
tl04	Today	4 KB	Alias
tl05	Today	4 KB	Alias
tl06	Today	4 KB	Alias
tl07	Today	4 KB	Alias
wrfbdy_d01	Today	4 KB	Alias
wrfinput_d01	Today	4 KB	Alias



Observations used by 4D-Var

- Conventional observational data

Observations used by 4D-Var

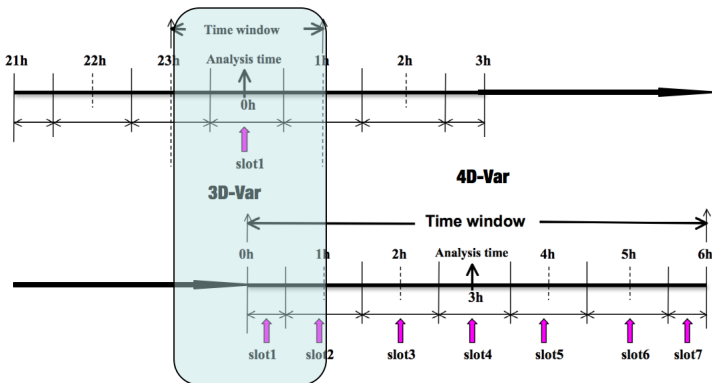
- Conventional observational data
- Radar radial velocity

Observations used by 4D-Var

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- Radiance satellite data (under testing)

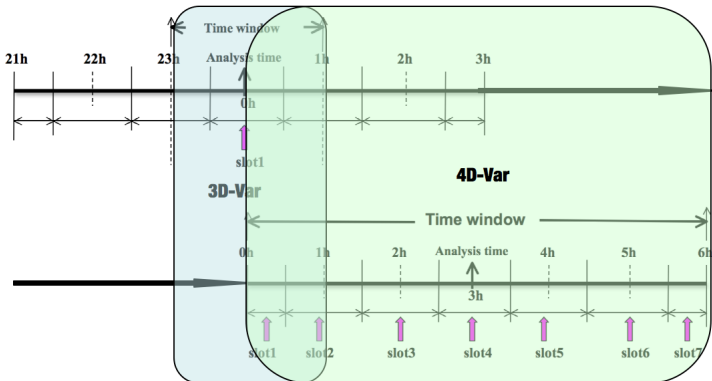
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Weak constraint with digital filter

$$J = J_b + J_o + J_c$$

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

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

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

where:

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

Weak constraint with digital filter

$$J = J_b + J_o + J_c$$

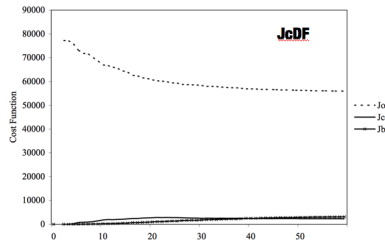
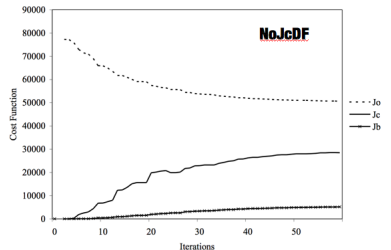
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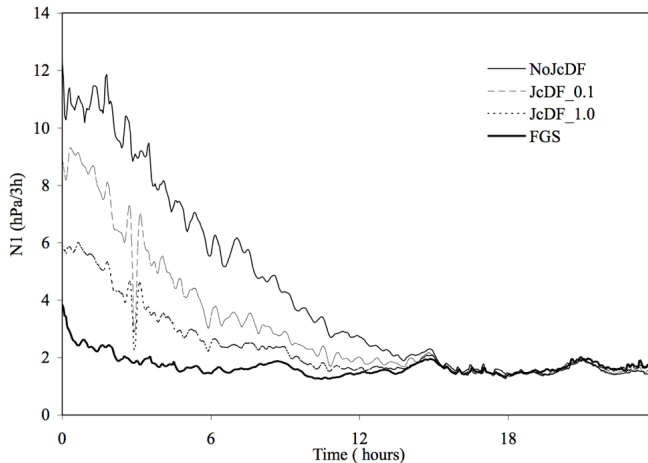
$$\begin{aligned} J_c(\mathbf{x}_0) &= \frac{\gamma_{df}}{2} \left[(\delta \mathbf{x}_{N/2} - \delta \mathbf{x}_{N/2}^{df})^T \mathbf{C}^{-1} (\delta \mathbf{x}_{N/2} - \delta \mathbf{x}_{N/2}^{df}) \right] \\ &= \frac{\gamma_{df}}{2} \left[\left(\delta \mathbf{x}_{N/2} - \sum_{i=0}^N f_i \delta \mathbf{x}_i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

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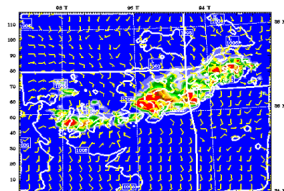
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- 4DVAR — 4DVAR analysis at 2002061301Z used as initial condition, and boundary condition from NCEP GFS. The radar radial velocity at 4 times: 200206130100, 05, 10, and 15, are assimilated (total data points = 262,445).

OSSE 3h precipitation simulation

Dataset: TRUTH REF: riprepdbs
Post: 3:00 h Valid: 0400 UTC Thu 13 Jan 02 Init: 0100 UTC Thu 13 Jan 02
Total precip. in past 1 h
Sea-level pressure
Horizontal velocity

TRUTH

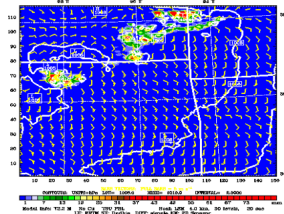
at k-index = 30



Dataset: 3DVAR REF: riprepdbs
Post: 3:00 h Valid: 0400 UTC Thu 13 Jan 02 Init: 0100 UTC Thu 13 Jan 02
Total precip. in past 1 h
Sea-level pressure
Horizontal velocity

3DVAR

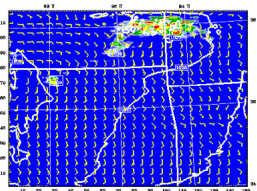
at k-index = 30



Dataset: NODA REF: riprepdbs
Post: 3:00 h Valid: 0400 UTC Thu 13 Jan 02 Init: 0100 UTC Thu 13 Jan 02
Total precip. in past 1 h
Sea-level pressure
Horizontal velocity

NODA

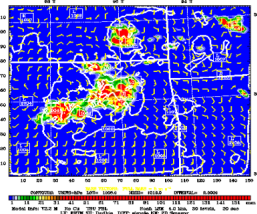
at k-index = 30



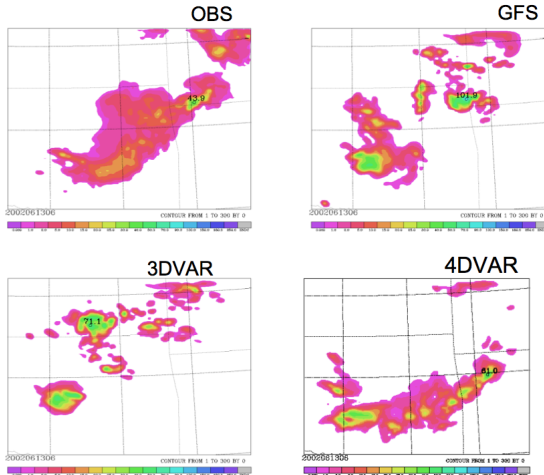
Dataset: 4DVAR REF: riprepdbs
Post: 3:00 h Valid: 0400 UTC Thu 13 Jan 02 Init: 0100 UTC Thu 13 Jan 02
Total precip. in past 1 h
Sea-level pressure
Horizontal velocity

4DVAR

at k-index = 30



Real Data Experiment



Quick Start

- Install WRFDA, WRFNL and WRFPLUS
 - WRFDA
 - WRFNL : WRF + some parallel controls designed for MPMD
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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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 - `csh, tcsh` : `setenv PGHPF_ZMEM yes`
 - `bash, ksh` : `export PGHPF_ZMEM = yes`

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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
```

Upgrading WRFPLUS

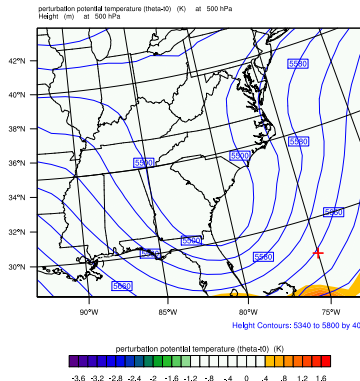
- New WRF adjoint and tangent linear codes based on the latest WRF codes.

Upgrading WRFPLUS

- New WRF adjoint and tangent linear codes based on the latest WRF codes.
- Significant computational performance improvement due to elimination of disk IO.

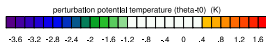
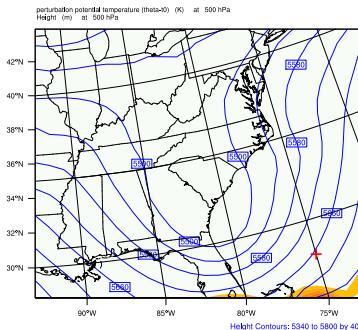
Consider Lateral boundary condition as control variable

perturbation potential T at 500hPa In: 2000-01-25_00:00:00

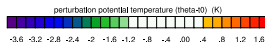
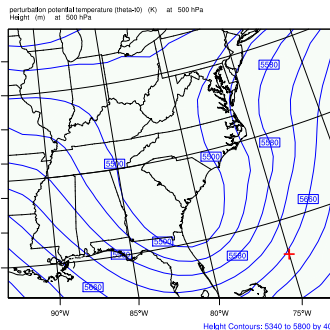


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perturbation potential T at 500hPa Init: 2000-01-25_00:00:00

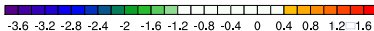
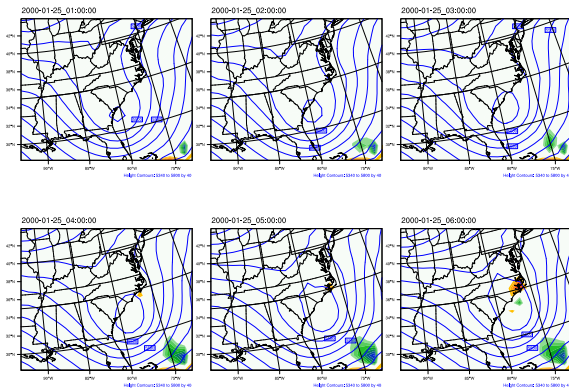


perturbation potential T at 500hPa Init: 2000-01-25_00:00:00



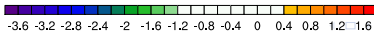
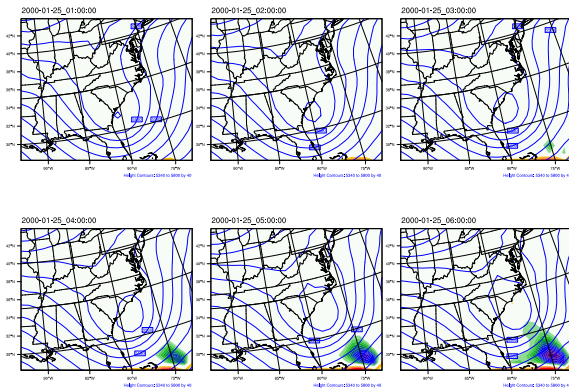
6h evolution w/o LBC control

perturbation potential T at 500 hPa (K)



6h evolution w/ LBC control

perturbation potential T at 500 hPa (K)





WRF 4D-Var Overview
WRF 4D-Var Applications
WRF 4D-Var Setup
Next generation WRF 4D-Var

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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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