Development of regional GSI-based WRF 4D-Var

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Outline

Acknowledgement

Sincere thanks to **Dr. Ricardo Todling** *for his help to kick off the project.*

Sincere thanks to **Dr. Thomas Auligne and Dr. Junmei Ban** *for their help and encouragement*

Current Status

- The development of GSI-based WRF 4D Var has been implemented in GSI Boulder's version of May 2011
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Sample 6h Tangent Linear and Adjoint Check

Taylor formula:

$$\lim_{\alpha \to 0} \frac{M(x + \alpha\delta\mathbf{x}) - M(x)}{M'(\alpha\delta\mathbf{x})} = 1$$

Tangent linear check

```
alpha_m=.1000E+00  coef=   0.98250076417818E+00  val_n= 0.3628649E+11  val_l= 0.3693279E+11
alpha_m=.1000E-01  coef=   0.99781045126907E+00  val_n= 0.3685192E+09  val_l= 0.3693279E+09
alpha_m=.1000E-02  coef=   0.99949153238165E+00  val_n= 0.3691401E+07  val_l= 0.3693279E+07
alpha_m=.1000E-03  coef=   0.10002560538015E+01  val_n= 0.3694225E+05  val_l= 0.3693279E+05
alpha_m=.1000E-04  coef=   0.99981685944643E+00  val_n= 0.3692603E+03  val_l= 0.3693279E+03
alpha_m=.1000E-05  coef=   0.10000972073298E+01  val_n= 0.3693638E+01  val_l= 0.3693279E+01
alpha_m=.1000E-06  coef=   0.99996624597337E+00  val_n= 0.3693154E-01  val_l= 0.3693279E-01
alpha_m=.1000E-07  coef=   0.99999992233716E+00  val_n= 0.3693279E-03  val_l= 0.3693279E-03
alpha_m=.1000E-08  coef=   0.10000017668820E+01  val_n= 0.3693285E-05  val_l= 0.3693279E-05
alpha_m=.1000E-09  coef=   0.10000050602279E+01  val_n= 0.3693298E-07  val_l= 0.3693279E-07
alpha_m=.1000E-10  coef=   0.10000451984913E+01  val_n= 0.3693446E-09  val_l= 0.3693279E-09
```

Adjoint identity:

$$\forall \mathbf{x}, \forall \mathbf{y} : \langle M'.\mathbf{x}, \mathbf{y} \rangle = \langle \mathbf{x}, \mathbf{M}^*.\mathbf{y} \rangle$$

Adjoint check

```
ad_check: VAL_TL:     0.42476489986911E+11
ad_check: VAL_AD:     0.42476489986912E+11
```

Modification in GSI

- Modified the capabilities to read and process multiple first guess and process obs. data for multiple time slots
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Modification in GSI contd

GSI Boulder repository revision 585, 2011-02-15

```
M       src/main/wrf_binary_interface.F90
M       src/main/read_wrf_mass_files.f90
M       src/main/control2model.f90
M       src/main/update_guess.f90
M       src/main/model_tl.F90
M       src/main/control2state.f90
M       src/main/model_ad.F90
M       src/main/stub_pertmod.F90
M       src/main/pcgsoi.f90
M       src/main/adjtest.f90
M       src/main/read_prepbufr.f90
M       src/main/gsi_4dvar.f90
A       src/main/wrf_pertmod.F90
M       src/main/wrwrfmassa.F90
M       src/main/wrf_netcdf_interface.F90
M       src/main/gsimod.F90
M       src/main/model2control.f90
M       src/main/state2control.f90
M       src/main/read_wrf_mass_guess.F90
M       src/main/evaljgrad.f90
M       src/main/Makefile.dependency
M       src/main/obsmod.F90
```

The New Module wrf_pertmod

The coupler and utilities used to couple GSI and WRFPLUS.

```
module wrf_pertmod
    subroutine model_nl_wrf            ! Subroutine to call WRF nonlinear model
    ...
    end subroutine model_nl_wrf
    subroutine model_tl_wrf             ! Subroutine to call WRF tangent linear model
    ...
    end subroutine model_tl_wrf
    subroutine model_ad_wrf            ! Subroutine to call WRF adjoint model
    ...
    end subroutine model_ad_wrf
    subroutine gsi2wrf_tl                  ! Transfer GSI perturbation to WRF perturbation
    ...
    end subroutine gsi2wrf_tl
    subroutine gsi2wrf_ad               !  Adjoint of gsi2wrf_tl
    ...
    end subroutine gsi2wrf_ad
    subroutine wrf2gsi_tl                 ! Transfer WRF perturbation to GSI perturbation
    ...
    end subroutine wrf2gsi_tl
    subroutine wrf2gsi_ad               ! Adjoint of wrf2gsi_tl
    ...
    end subroutine wrf2gsi_ad
end module wrf_pertmod
```

Quick Start

Install WRFPLUS and GSI

1. WRFPLUS : WRF adjoint and tangent linear codes

   ```
   > configure [-d] wrfplus
   > compile em_real
   ```

2. Set the the WRF_DIR environmental variable

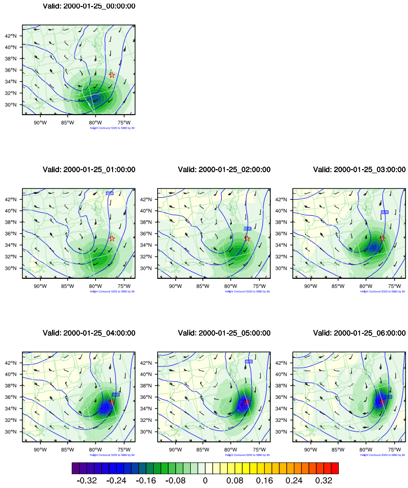
   ```
   > setenv WRF_DIR full_path_of_wrfplus
   ```

3. GSI

   ```
   > configure
   > compile
   ```

Single observation exp. I

- Initial time: 2000_01_25_00 : 00 : 00
- Ending time: 2000_01_25_06 : 00 : 00
- Observation: 500 mb Temperature at ending time
  $O - B = -1.15K$
- To investigate the difference at ending time between the forecast from analysis and from background.

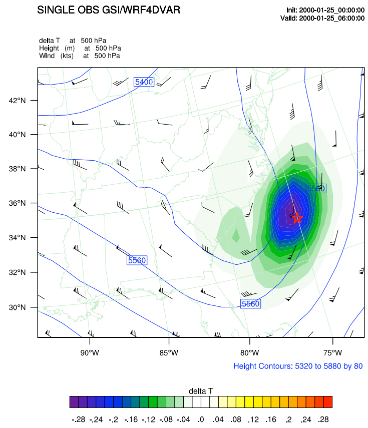


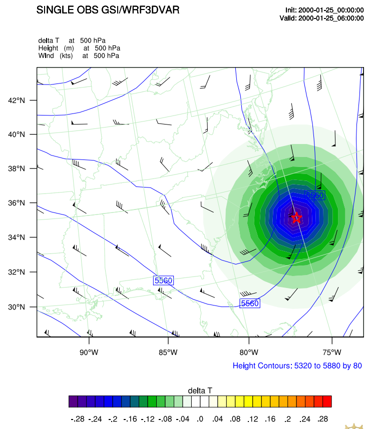
Remarks

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
- Very obvious flow dependent characteristics

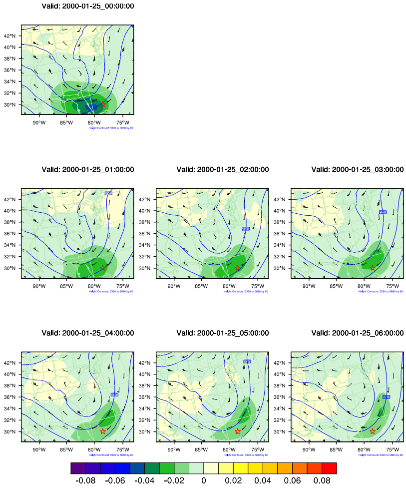
Analysis increment comparison valid@6h—4DVAR and 3DVAR





Single observation exp. II

- Initial time: 2000_01_25_00 : 00 : 00
- Ending time: 2000_01_25_06 : 00 : 00
- Observation: 500 mb Temperature at ending time
  $O - B = -1.04K$
- To investigate the impact of an observation close to boundary.

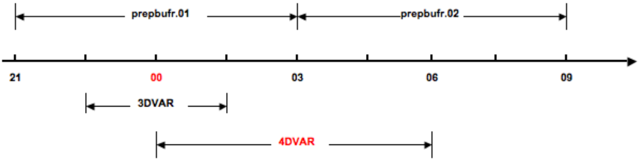


Remarks

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 miss the obs. location
- Without LBC control, it is hard to fit the obs.

Tutorial case – Observation Usage



3DVAR

```
0:OBS_PARA: ps       13842
0:OBS_PARA: t        20114
0:OBS_PARA: q        18743
0:OBS_PARA: uv       30894
0:OBS_PARA: spd         48
0:OBS_PARA: sst        503
0:OBS_PARA: pw         880
---------------Total------------------
47675
```

4DVAR

```
0:OBS_PARA: ps       13585
0:OBS_PARA: t        20639
0:OBS_PARA: q        19180
0:OBS_PARA: uv       28802
0:OBS_PARA: spd         80
0:OBS_PARA: sst        494
0:OBS_PARA: pw         766
------------------------------
0:OBS_PARA: ps          10
0:OBS_PARA: t          552
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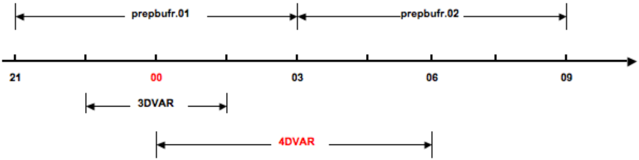

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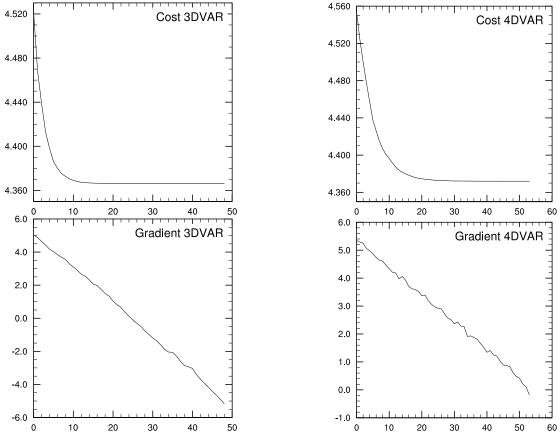
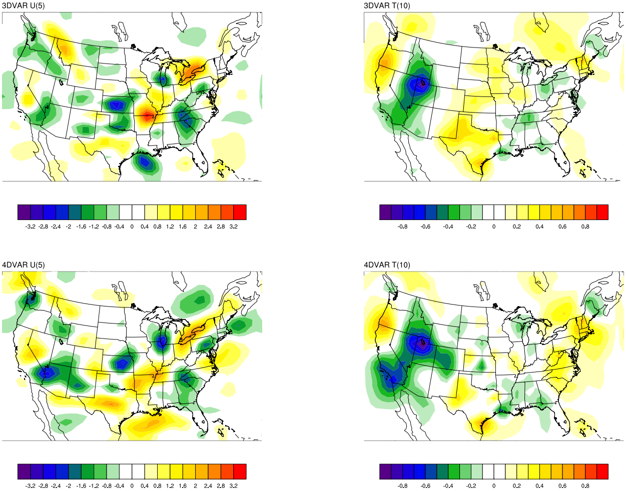
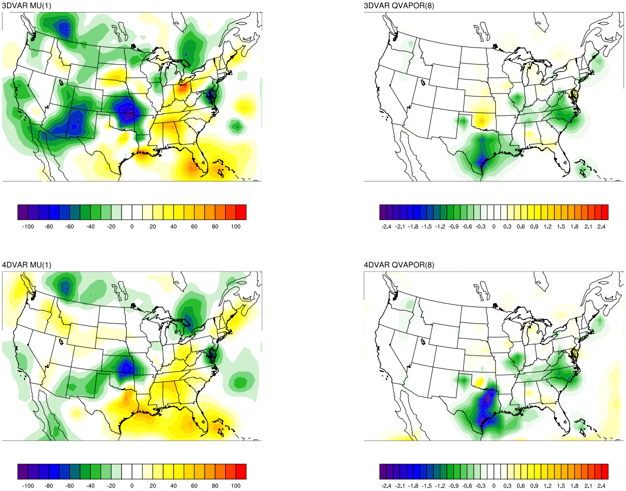
Cost functions and gradients –scaled by ALOG10



Sample increments comparison – U, T

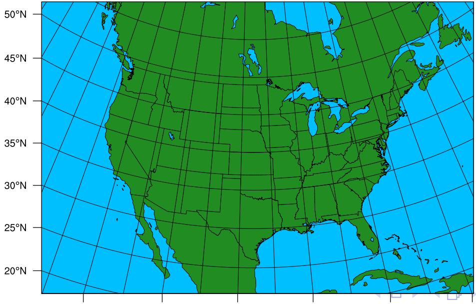


Sample increments comparison – MU, QVAPOR

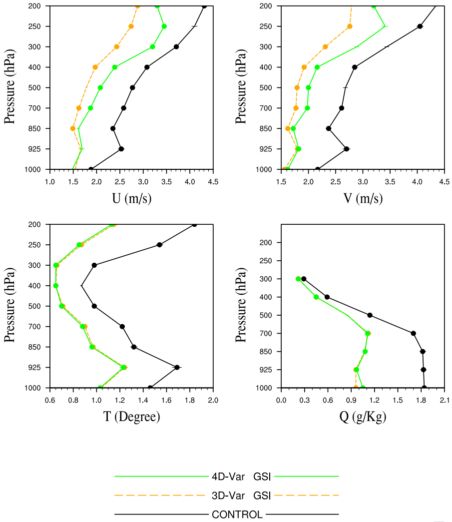


Experiment configuration

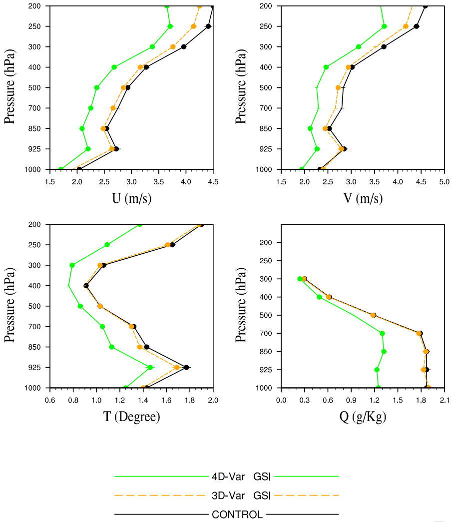
- Grids: 105x72x28L
- Resolution: 60km
- Period: 2007091100-2007092600 @0Z,6Z,12Z,18Z
- First guess is the 12h forecast from NCEP FNL
- 48h forecast from FG, 3DVAR and 4DVAR
- Verified against NCAR archived little_r format data, filtered by FNL.



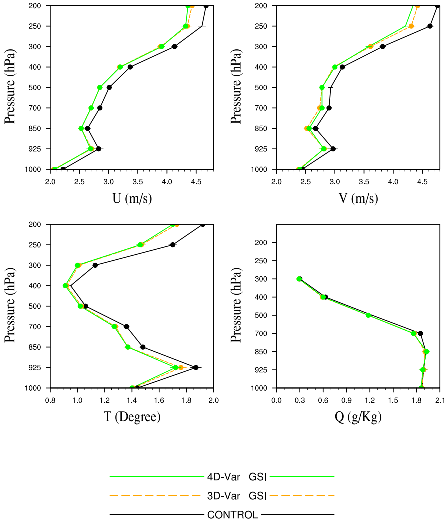
RMSE Verification—00h



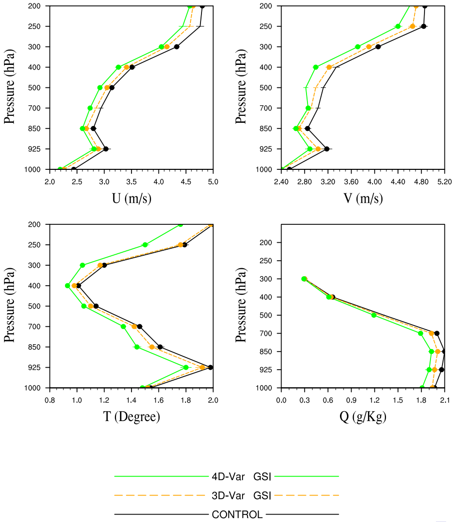
RMSE Verification—06h



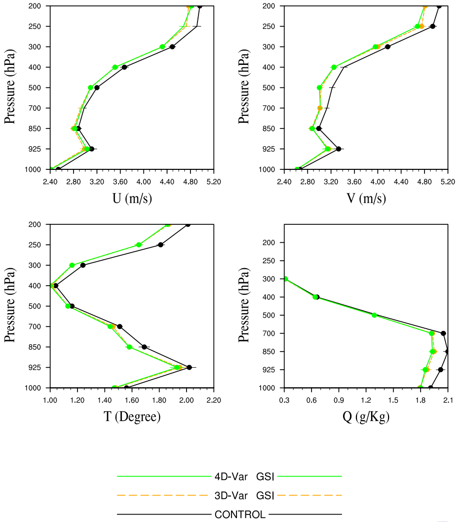
RMSE Verification—12h



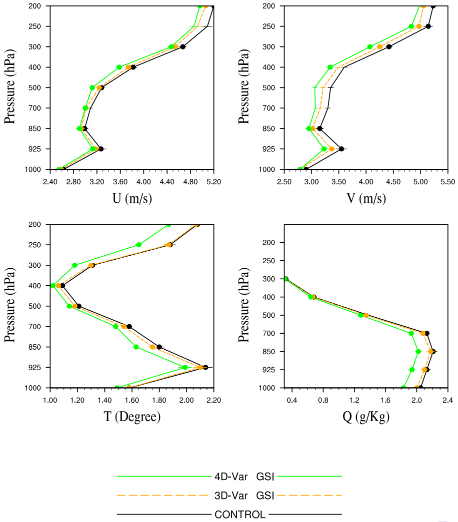
RMSE Verification—18h



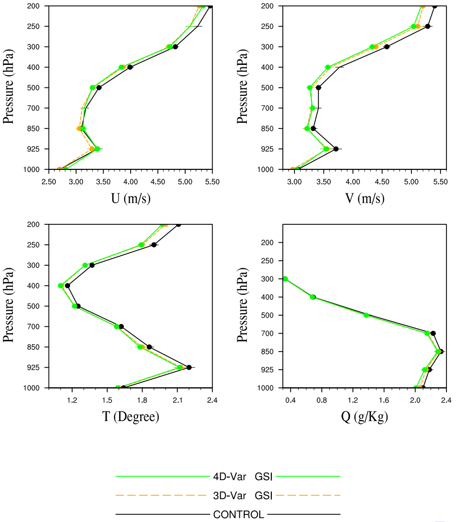
RMSE Verification—24h



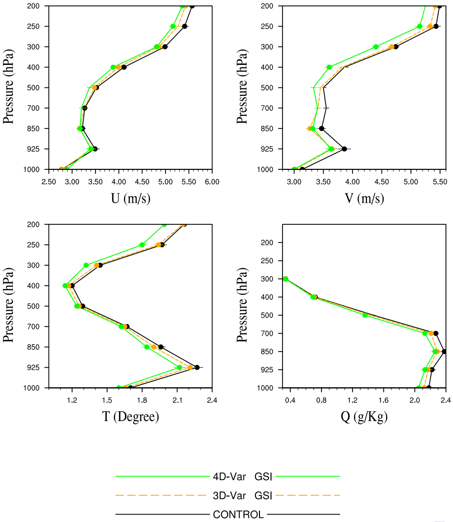
RMSE Verification—30h



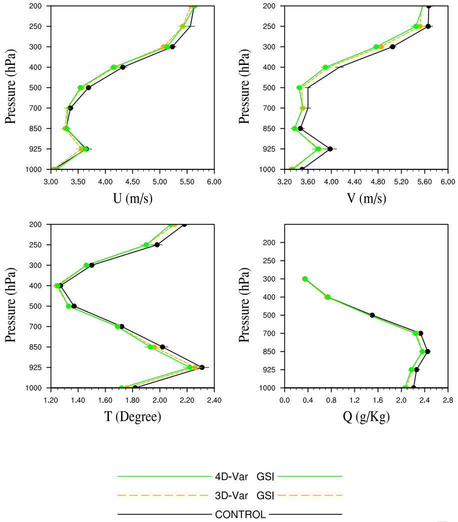
RMSE Verification—36h



RMSE Verification—42h



RMSE Verification—48h



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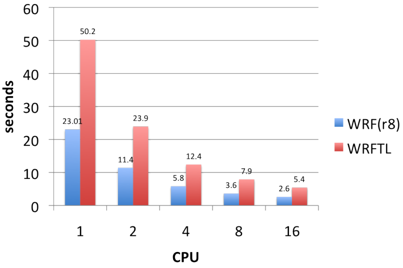

One-time step timing

- 350x250x57L @27KM, time_step=150s
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- 64G Memory
- 8 Processors , 8 cores/processor
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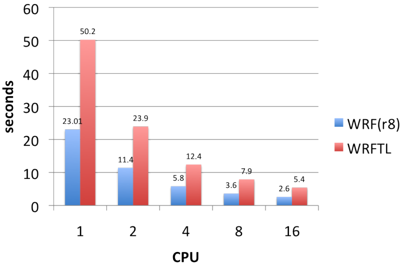

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Thank You

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

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