Report on the development of GSI-based WRF 4DVAR

Xin Zhang Xiang-Yu Huang

NCAR Earth System Laboratory

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Outline

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Acknowledgement

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

Sincere thanks to **Dr. Thomas Auligne, Dr. Junmei Ban, Mrs. Xiaoyan Zhang and Mr. Feng Gao** *for their help and encouragement*

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- The Major development in GSI had finished, GSI codes had been coupled with the WRF tangent linear and adjoint model
- The WRF tangent linear and adjoint codes (hereafter, WRFPLUS) have been updated to be consistent with the latest WRF repository codes
- Because the parallelization of the latest WRFPLUS is still on going, only 1 processor parallel run is doable at this moment

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- Add capability to do tangent linear check and adjoint test over any length of time window.
- Add option to control if all inputs and outputs were happen in disk or memory, so WRFPLUS can be used as a standalone tool or as a component in 4DVAR system.

Sample 6h Tangent Linear and Adjoint Check

Tangent linear check

```
...
tl_check: alpha=.1000E-04  coef=0.1000447262220E+01
tl_check: alpha=.1000E-05  coef=0.9999981575068E+00
tl_check: alpha=.1000E-06  coef=0.9999998152933E+00
tl_check: alpha=.1000E-07  coef=0.9999999080017E+00
tl_check: alpha=.1000E-08  coef=0.9999956711797E+00
...
```

Adjoint check

```
ad_check: VAL_TL:     0.4247648998691 1E+11
ad_check: VAL_AD:     0.4247648998691 2E+11
```

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- Added WRF TL/AD subroutines calling interface in model_tl and model_ad
- Added capability to do adjoint test with WRF AD/TL.

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

- WRFPLUS : WRF adjoint and tangent linear codes

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

- Set the the WRF_DIR environmental variable

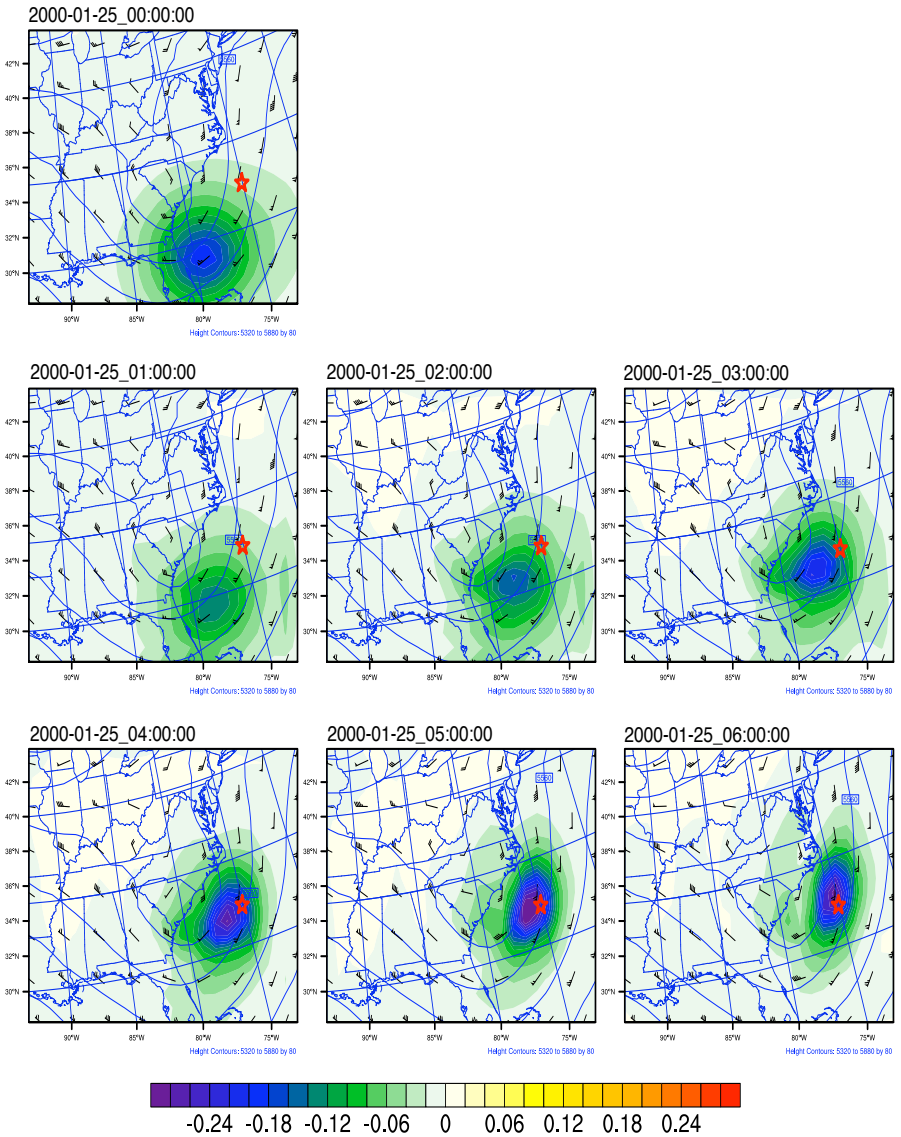
```
> setenv WRF_DIR full_path_of_wrfplus
```

- GSI

```
> configure
> compile
```

Single observation exp.

- Initial time: $2000\_01\_25\_00:00:00$
- Ending time: $2000\_01\_25\_06:00:00$
- Observation: 500 mb Temperature at ending time
  $O - B = -1.17K$
- To investigate the difference at ending time between the forecast from analysis and from background.

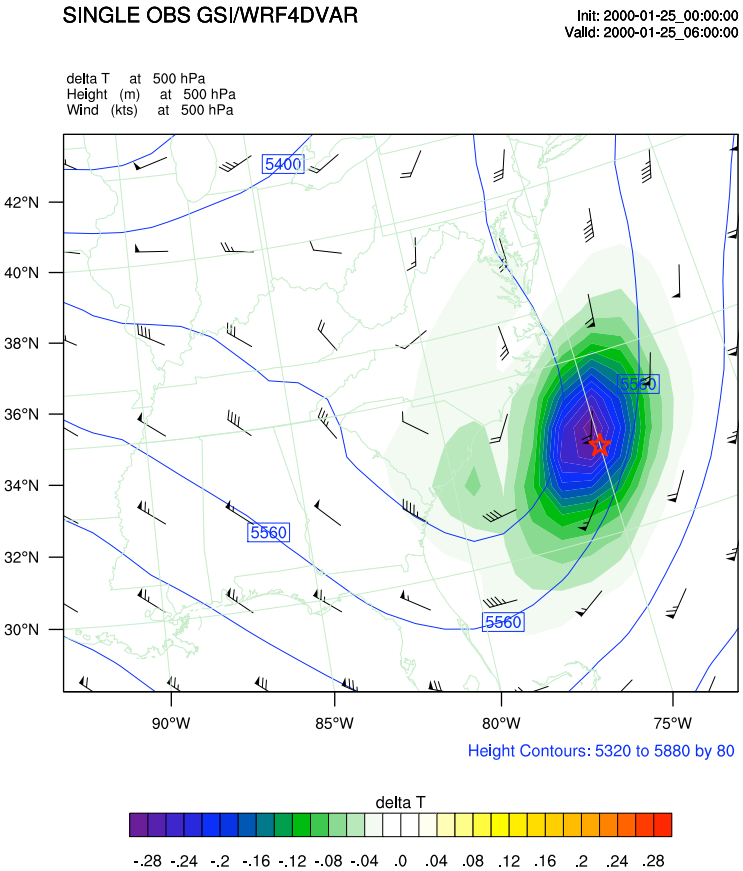


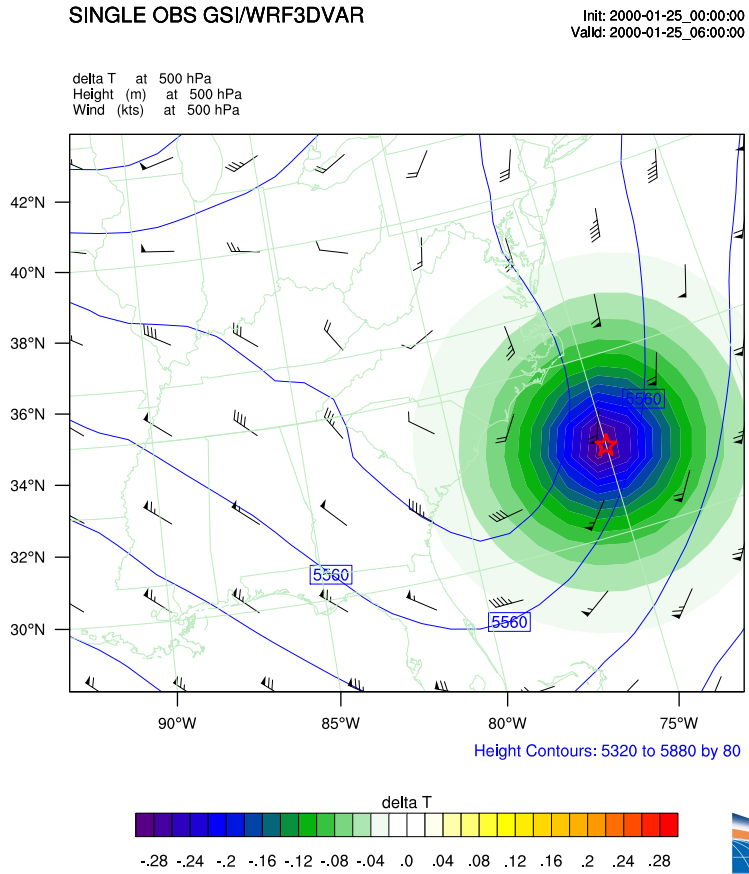
Remarks

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

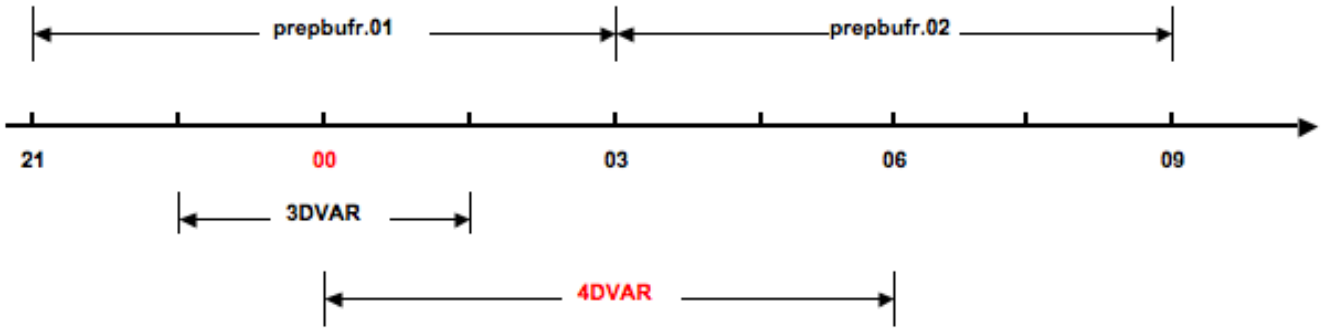
- $\star$ is the location of obs. at the ending time (6h).
- Initial perturbation is on the upstream of the obs.
- Evolved perturbation at 6h hit the obs. location
- Very obvious flow dependent characteristics

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





Tutorial case – Observation Usage



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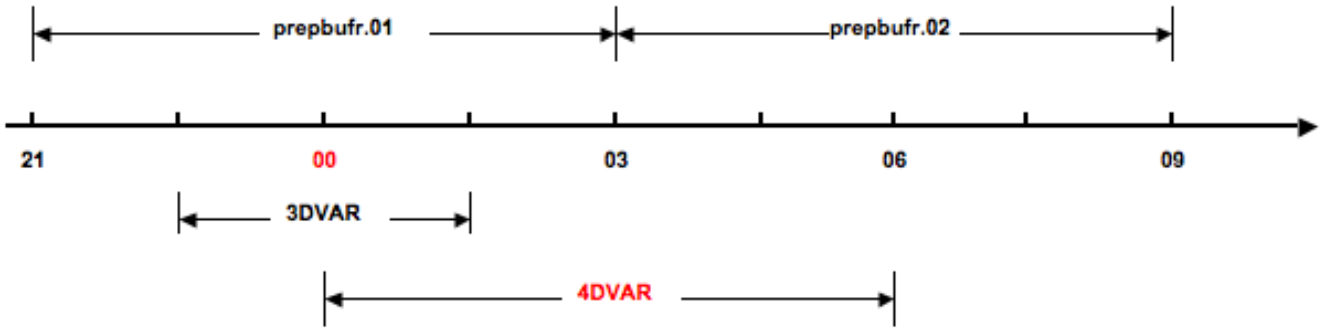


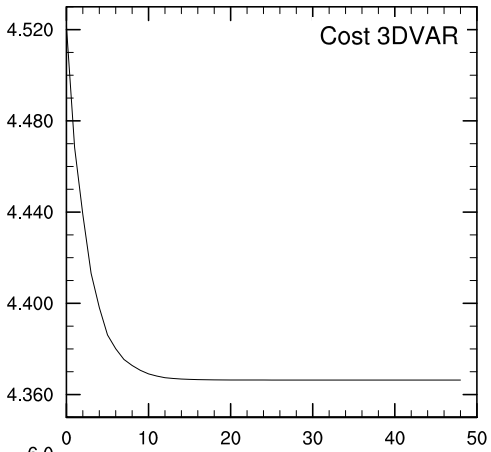
3DVAR

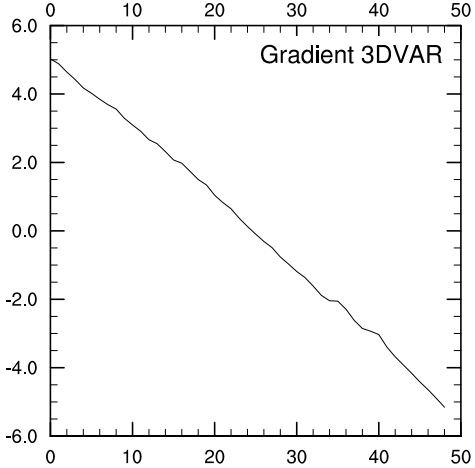
```
0:OBS_PARA: ps                    13842
0:OBS_PARA: t                     20114
0:OBS_PARA: q                     18743
0:OBS_PARA: uv                    30894
0:OBS_PARA: spd                      48
0:OBS_PARA: sst                     503
0:OBS_PARA: pw                      880
---------------Total-------------------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

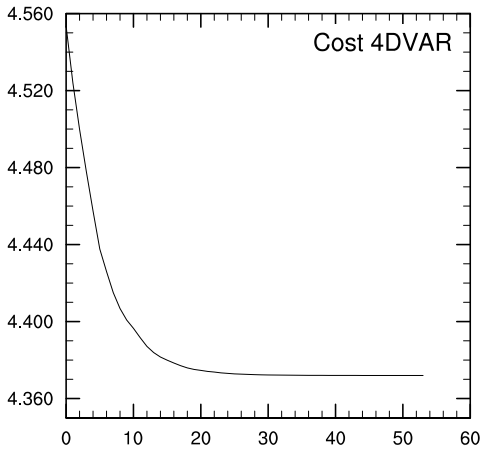
4DVAR

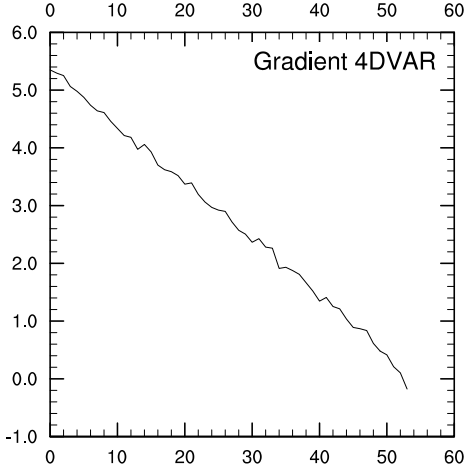
```
0:OBS_PARA: ps                    13585
0:OBS_PARA: t                     20639
0:OBS_PARA: q                     19180
0:OBS_PARA: uv                    28802
0:OBS_PARA: spd                      80
0:OBS_PARA: sst                     494
0:OBS_PARA: pw                      766
-----------------------------
0:OBS_PARA: ps                       10
0:OBS_PARA: t                       552
0:OBS_PARA: q                       490
0:OBS_PARA: uv                      568
---------------Total-------------------
45040 ???
```

Cost functions and gradients –scaled by ALOG10



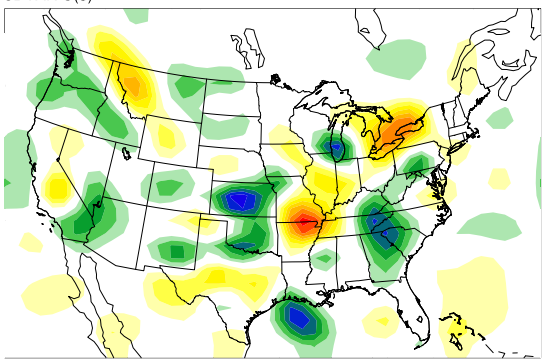




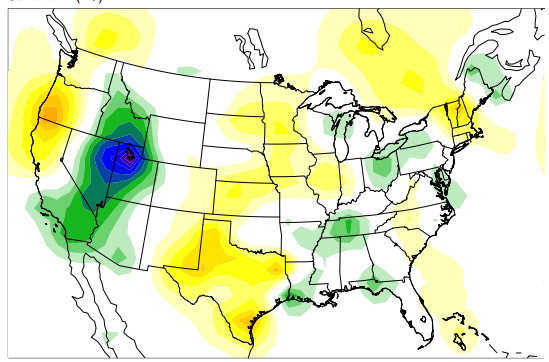


Sample increments comparison – U, T

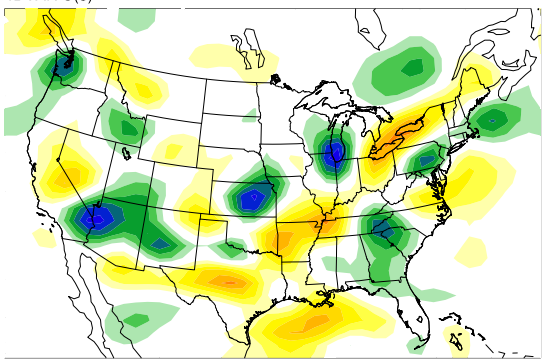
3DVAR U(5)



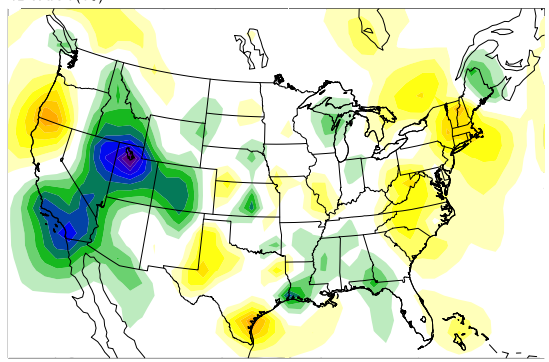
3DVAR T(10)



4DVAR U(5)

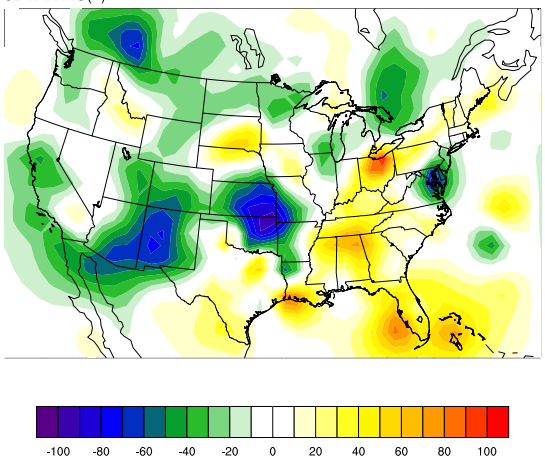


4DVAR T(10)

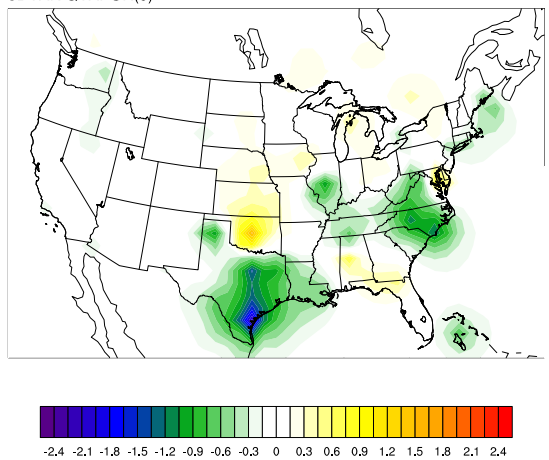


Sample increments comparison – MU, QVAPOR

3DVAR MU(1)



3DVAR QVAPOR(8)



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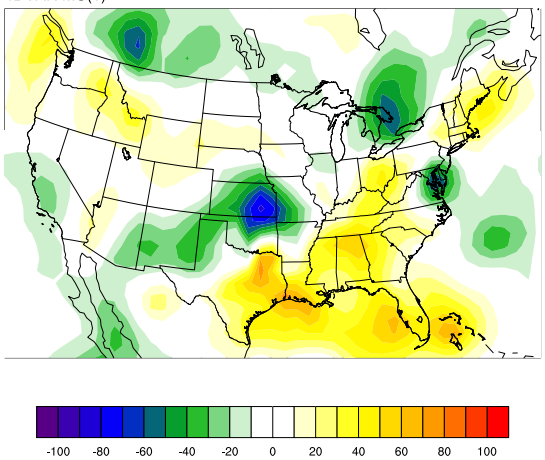
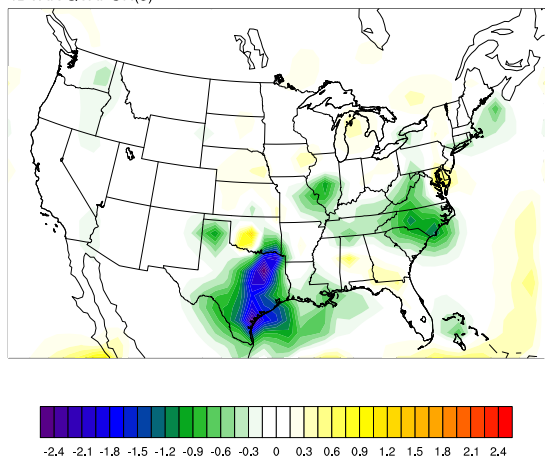
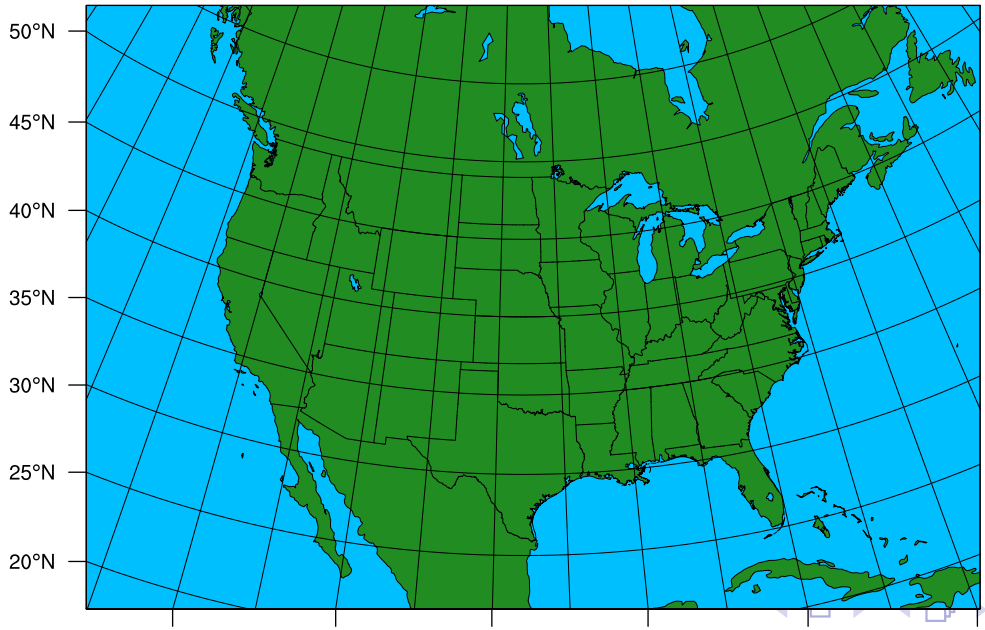


4DVAR QVAPOR(8)

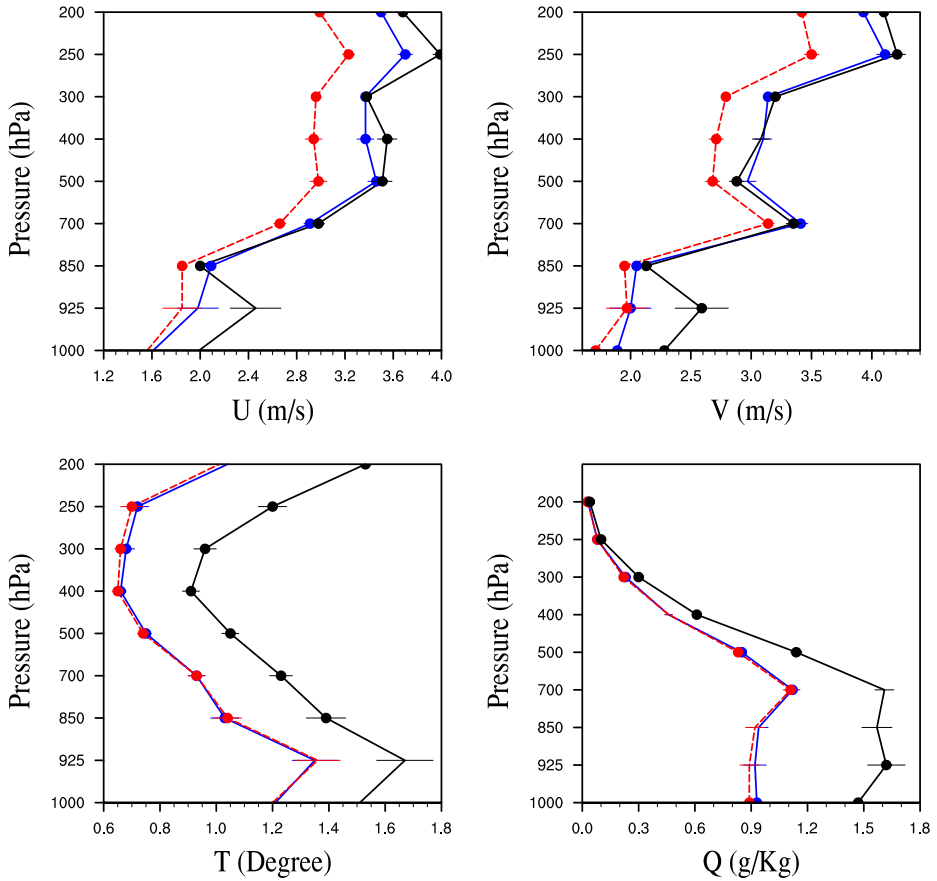


Domain

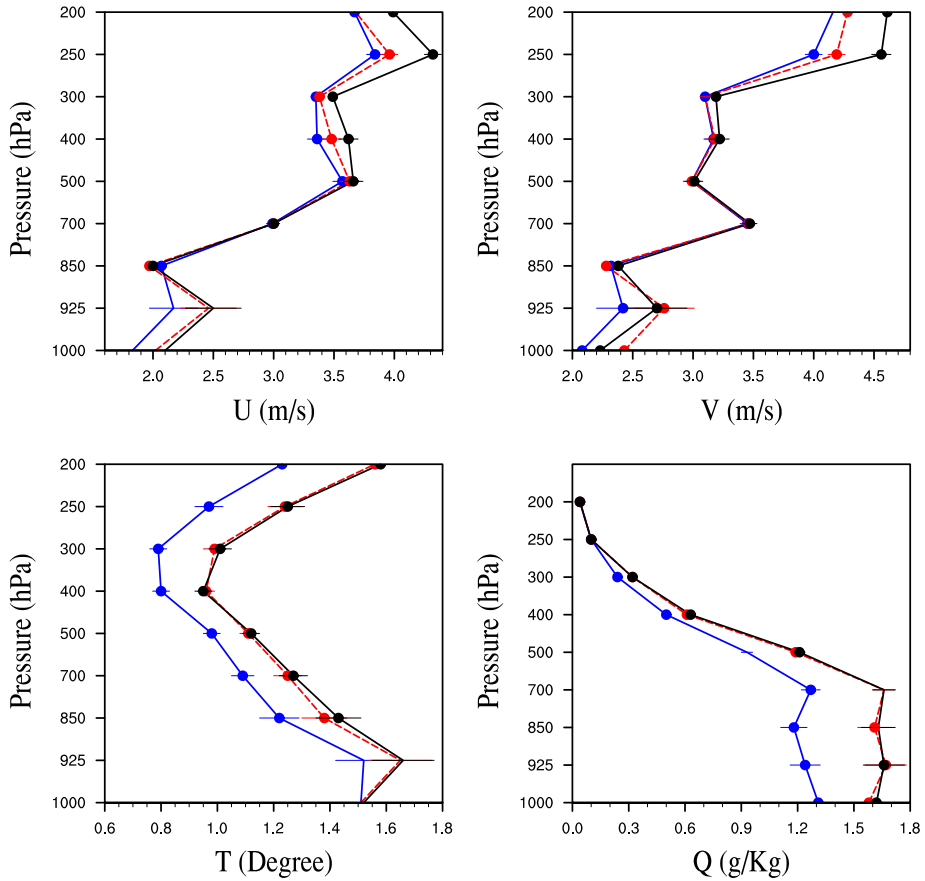
- Grids: 47x32x28L
- Resolution: 135km
- Period: 2007091000-2007091300 @0Z,6Z,12Z,18Z
- First guess is the 12h forecast from NCEP FNL
- 48h forecast from FG, 3DVAR and 4DVAR
- Verified against NCAR archived little_r format data, filtered by FNL.



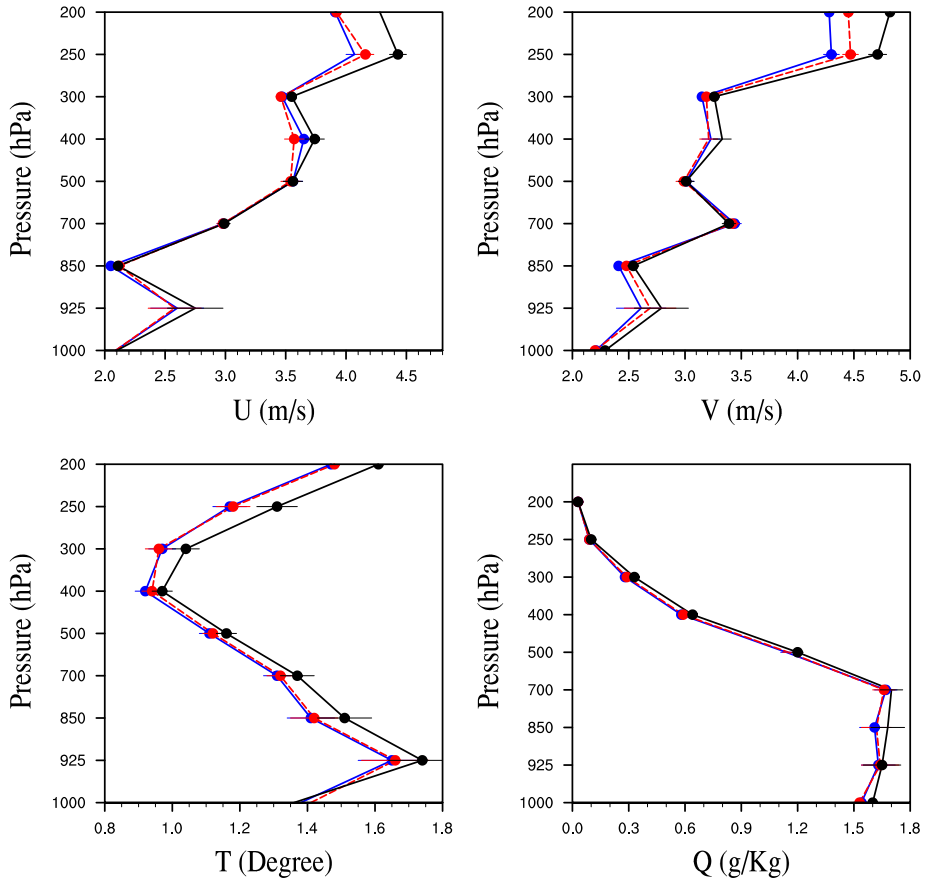
RMSE Verification—00h



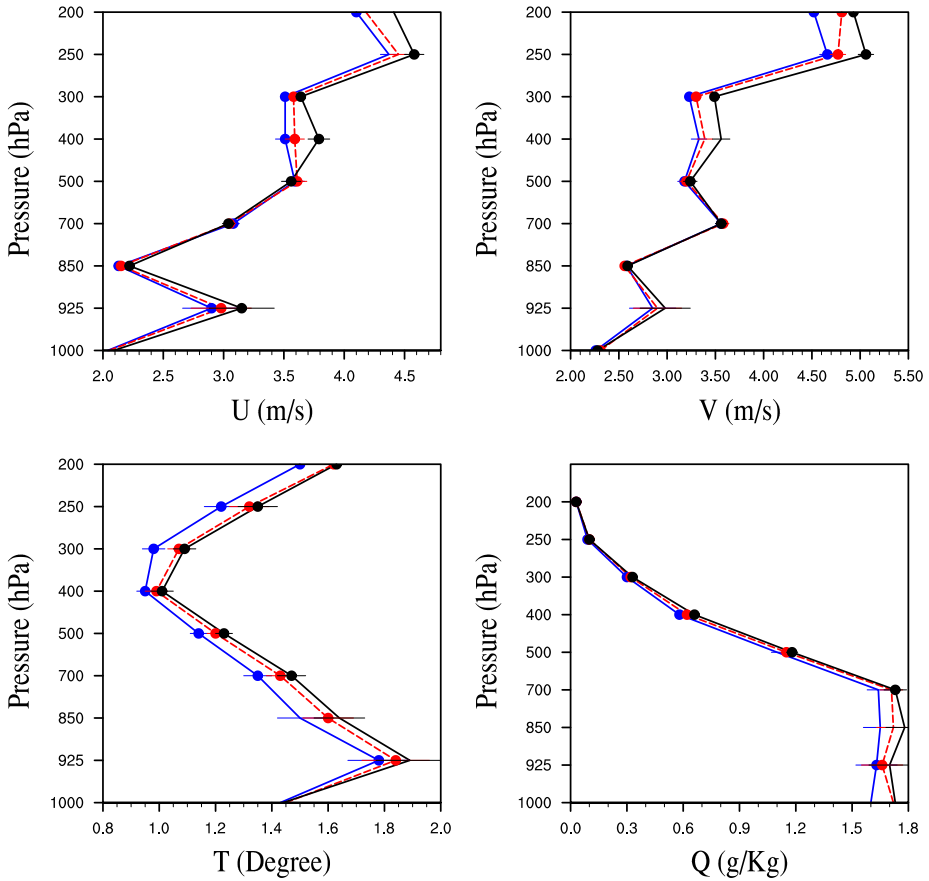
RMSE Verification—06h



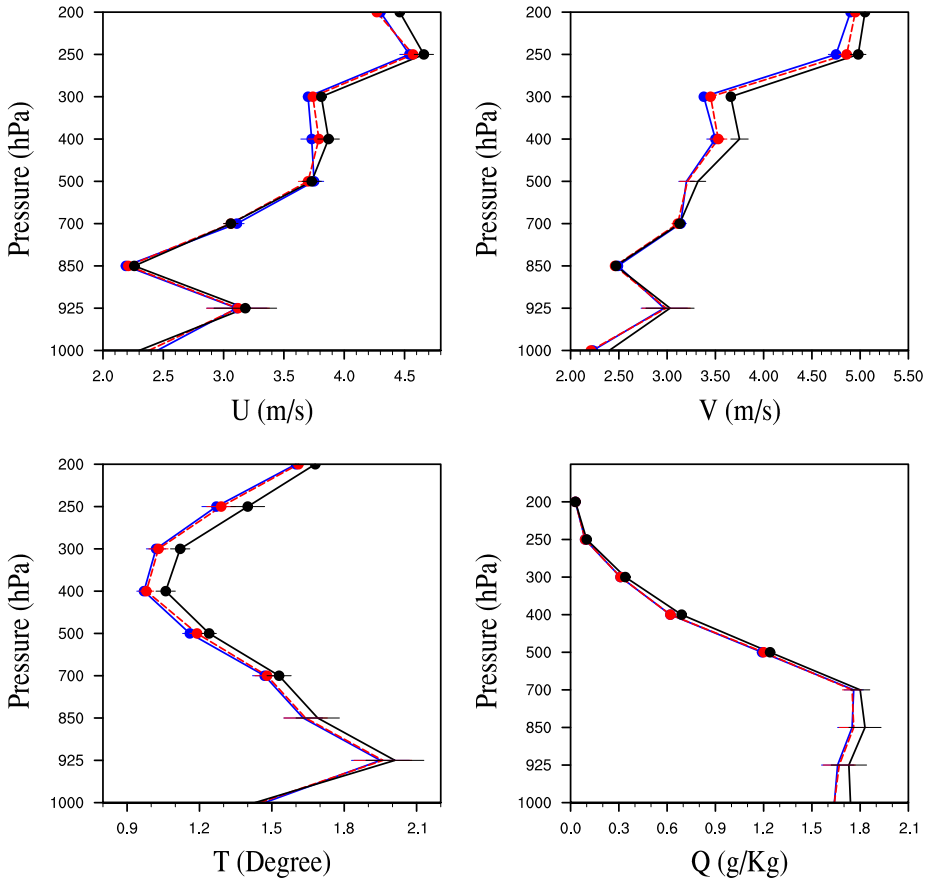
RMSE Verification—12h



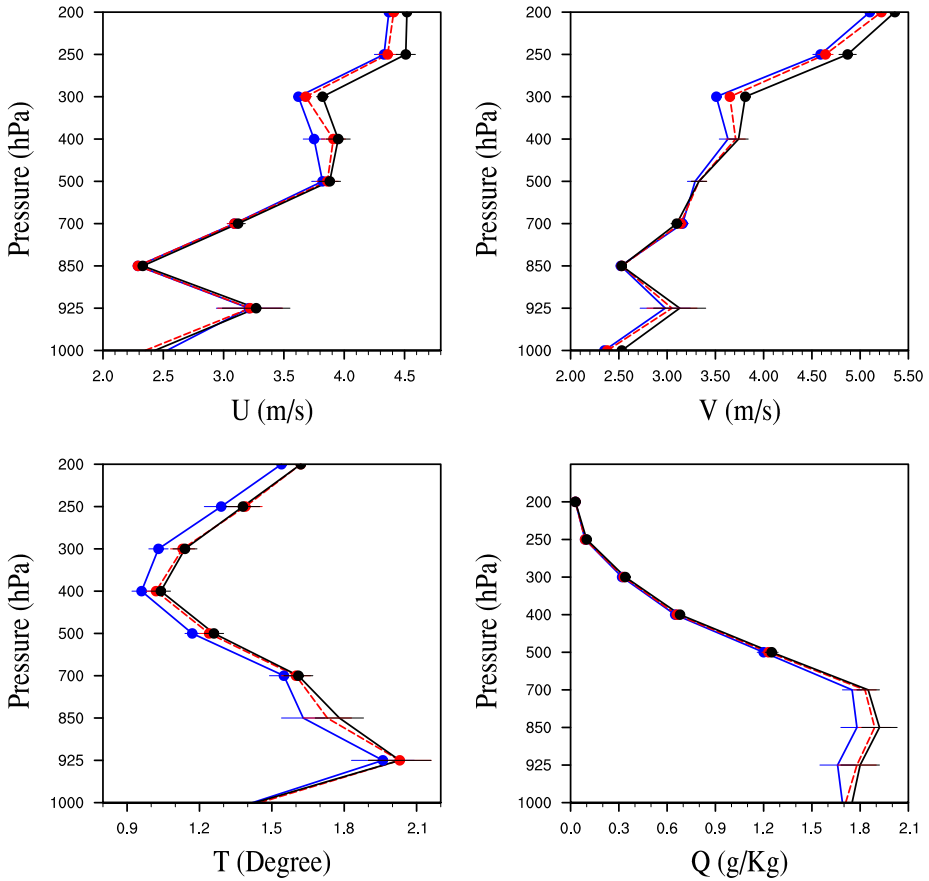
RMSE Verification—18h



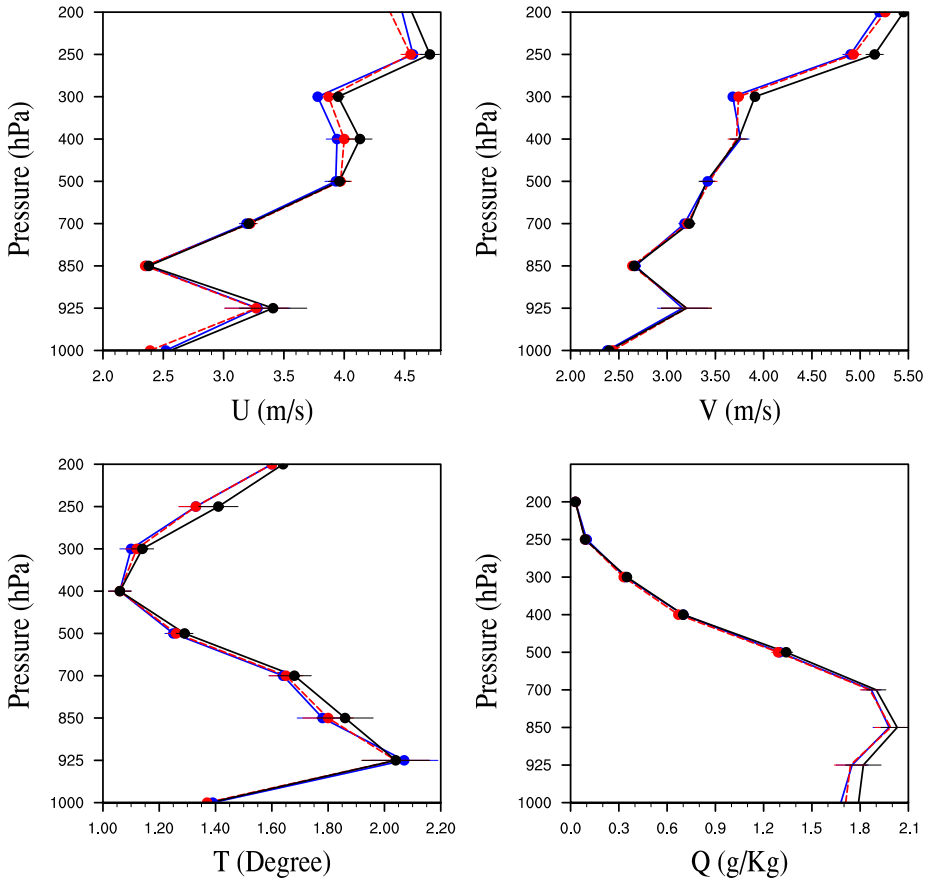
RMSE Verification—24h



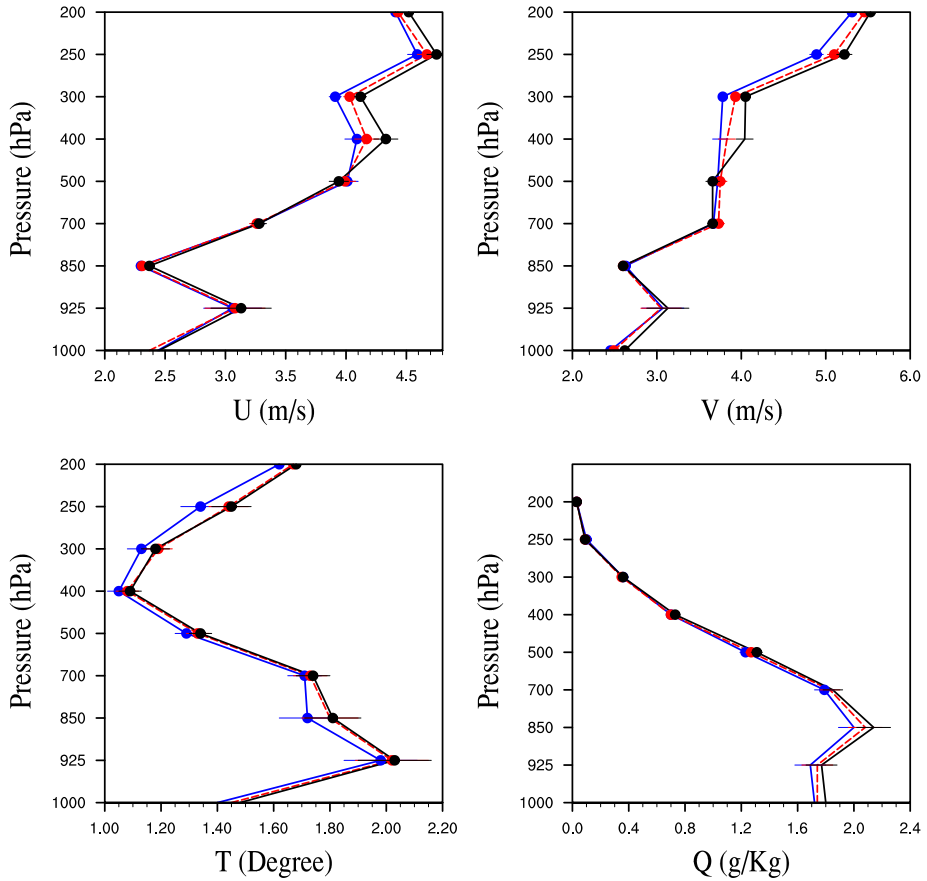
RMSE Verification—30h



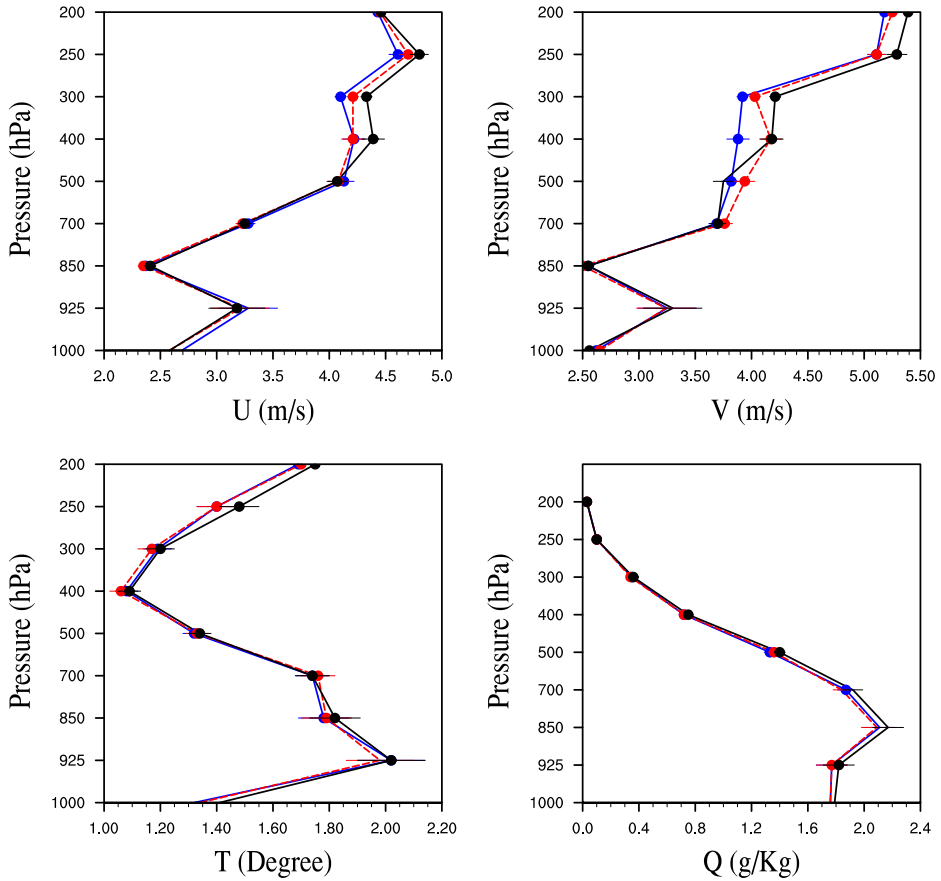
RMSE Verification—36h



RMSE Verification—42h



RMSE Verification—48h



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- The real case shows the desirable performance of 4DVAR.

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- Adjoint check achieved 5-digital identical, need to debug the code to find the bugs.
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- Assimilation of radiance data.
- Adapt gradient check for GSI-based WRF 4DVAR.
- Adapt digital filter as a weak constrain for GSI-based WRF 4DVAR.

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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