

Development of regional GSI-based WRF 4D-Var

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Outline

1 Introduction



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2 WRFPLUS V3.3



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- ② WRFPLUS V3.3
- ③ New developments in GSI



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- ④ GSI/WRF 4DVAR System Validation
 - Single observation exp. I
 - Single observation exp. II
 - Tutorial case
 - Real case



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- ⑤ Summary



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 has been coupled with the WRF tangent linear and adjoint model
- Because the parallelization of the latest WRFPLUS V3.3 is still on going, only 1 processor parallel run is allowed at this moment



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- Adding option to control where are the inputs and outputs (disk or memory), so WRFPLUS V3.3 can be used as a standalone tool or as a component in 4D-Var system.



Sample 6h Tangent Linear and Adjoint Check

Taylor formula:

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

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:

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

Adjoint check

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



Modification in GSI

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- Added subroutine interfaces in model_tl and model_ad to call WRF tangent linear and adjoint model directly.
- 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_t1.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/wrwrflmassa.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

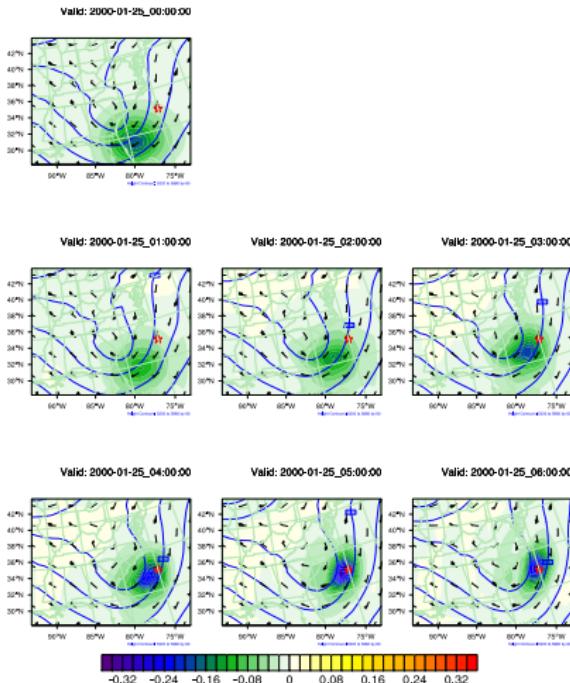
- WRFPLUS : WRF adjoint and tangent linear codes
 - > `configure [-d] wrfplus`
 - > `compile em_real`
- Set the the *WRF_DIR* environmental variable
 - > `setenv WRF_DIR full_path_of_wrfplus`
- GSI
 - > `configure`
 - > `compile`



Single observation exp. 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)

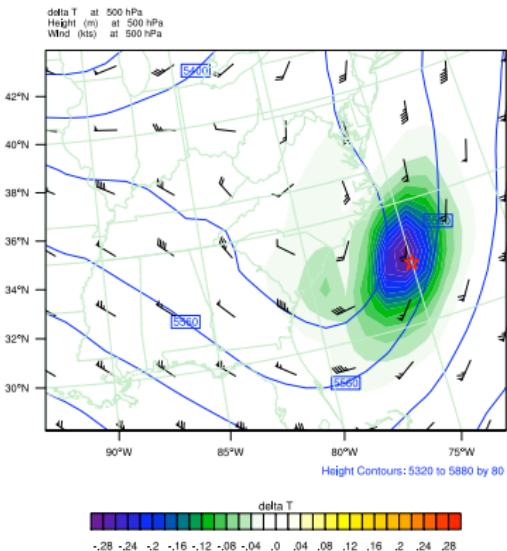
- ★ is the location of obs. at the ending time (6h).
- Initial perturbation is on the upstream of the obs.
- Evolved perturbation at 6h hit the obs. location
- Very obvious flow dependent characteristics



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

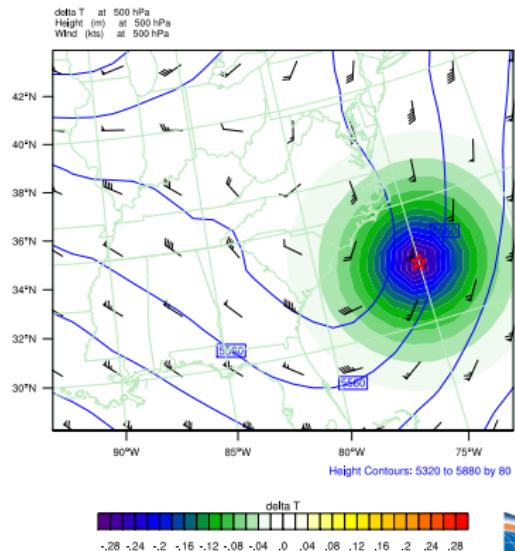
SINGLE OBS GSI/WRF4DVAR

Init: 2000-01-25_00:00:00
Valid: 2000-01-25_06:00:00



SINGLE OBS GSI/WRF3DVAR

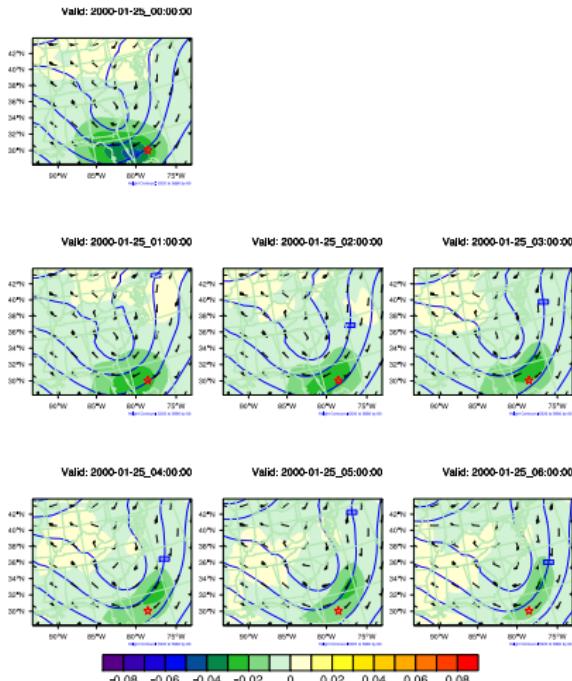
Init: 2000-01-25_00:00:00
Valid: 2000-01-25_06:00:00



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.





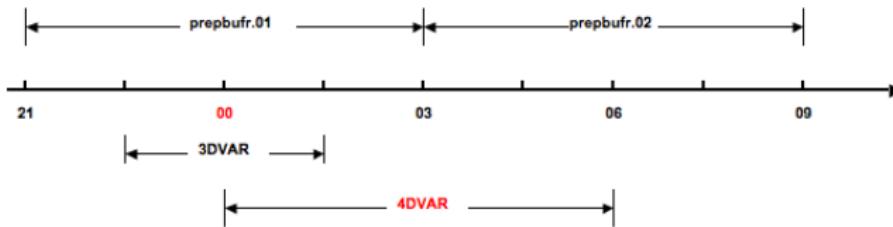
Remarks

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

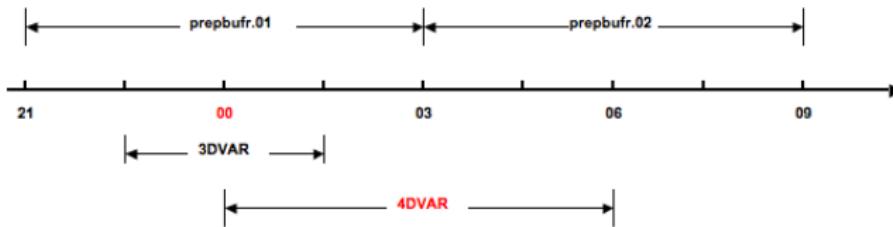
- ★ is the location of obs. at the ending time (6h).
- Initial perturbation is on the upstream of the obs.
- Evolved perturbation at 6h miss the obs. location
- Without LBC control, it is hard to fit the obs.



Tutorial case – Observation Usage



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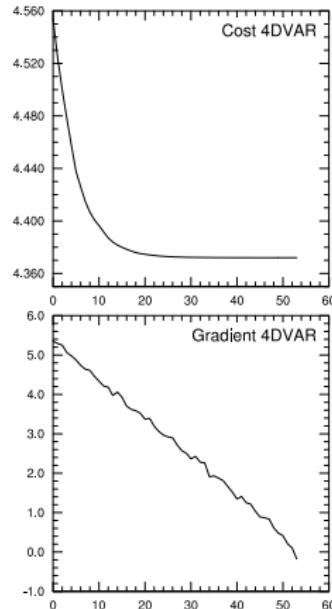
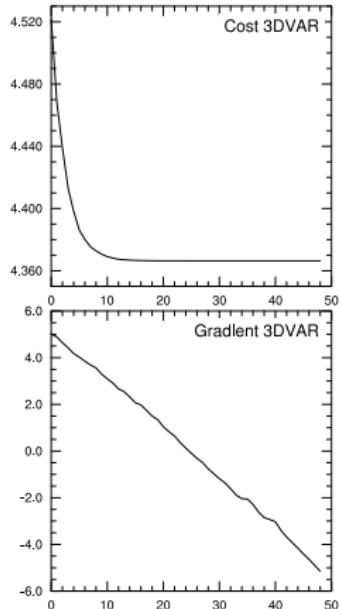
3DVAR

| | |
|-----------------|-------|
| 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 | |

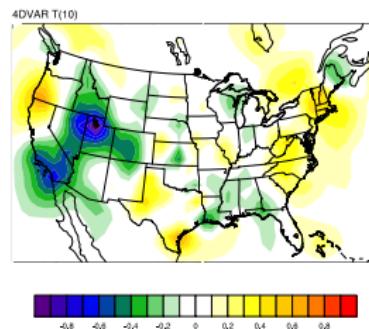
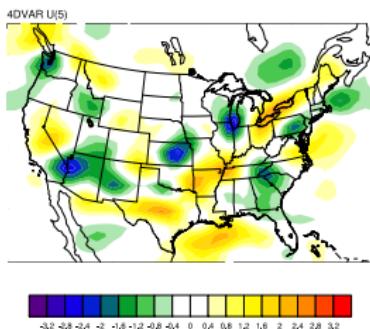
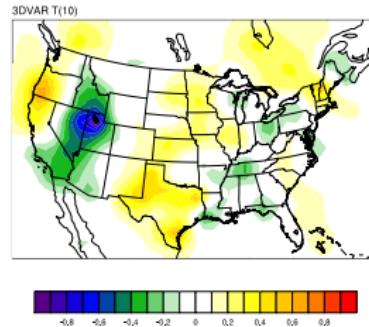
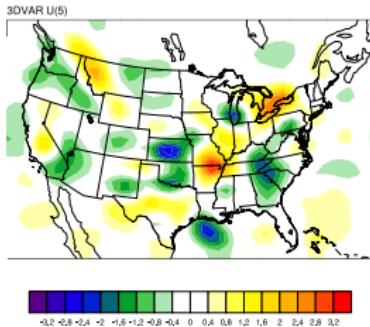
4DVAR

| | |
|-----------------|-------|
| 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 | |

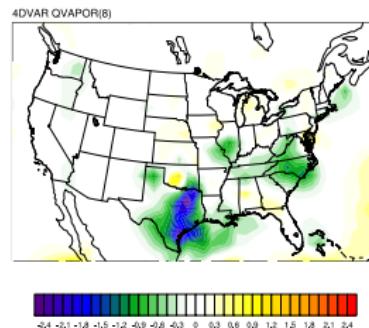
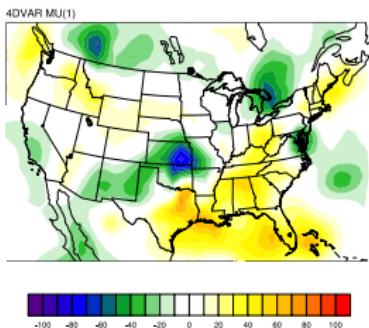
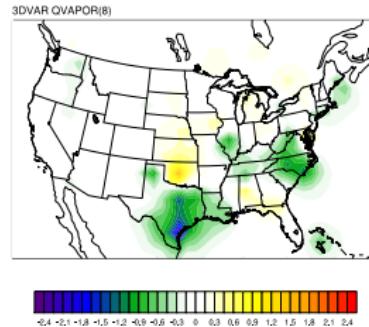
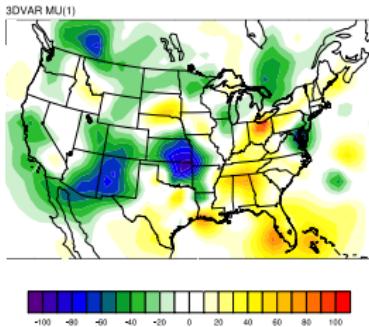
Cost functions and gradients –scaled by ALOG10



Sample increments comparison – U, T

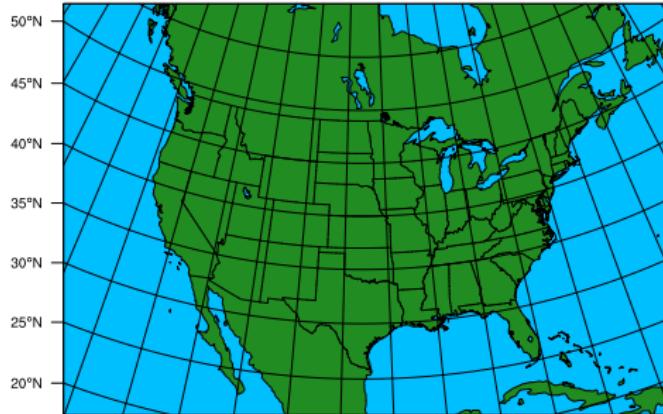


Sample increments comparison – MU, QVAPOR

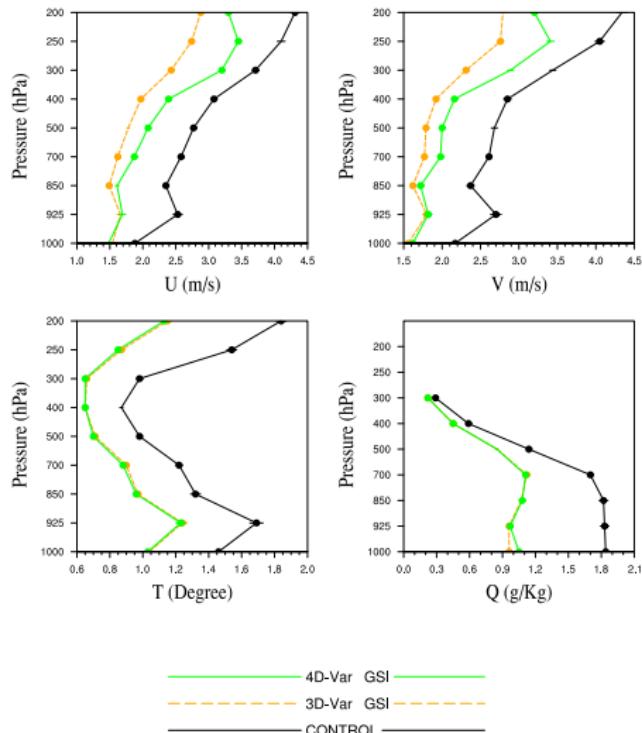


Experiment configuration

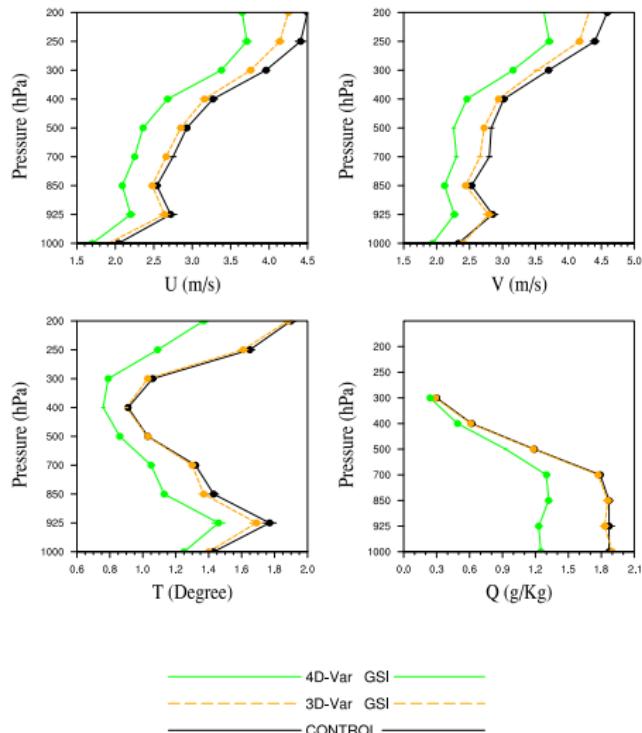
- Grids: 105x72x28L
- Resolution: 60km
- Period: 2007091100-2007092600 @0Z,6Z,12Z,18Z
- First guess is the 12h forecast from NCEP FNL
- 48h forecast from FG, 3DVAR and 4DVAR
- Verified against NCAR archived little_r format data, filtered by FNL.



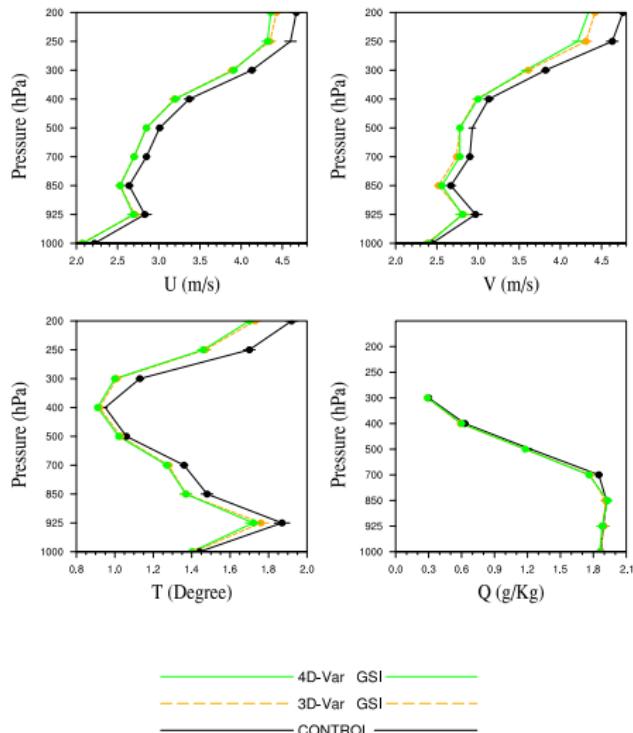
RMSE Verification—00h



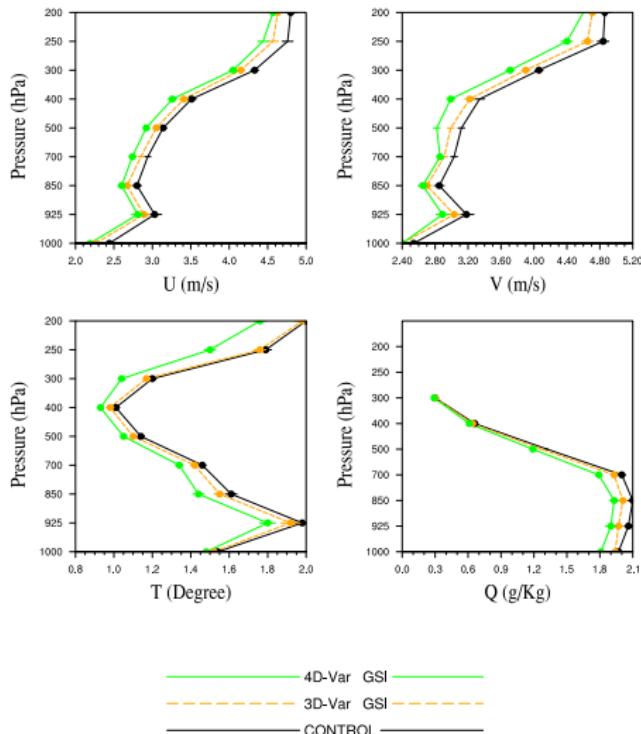
RMSE Verification—06h



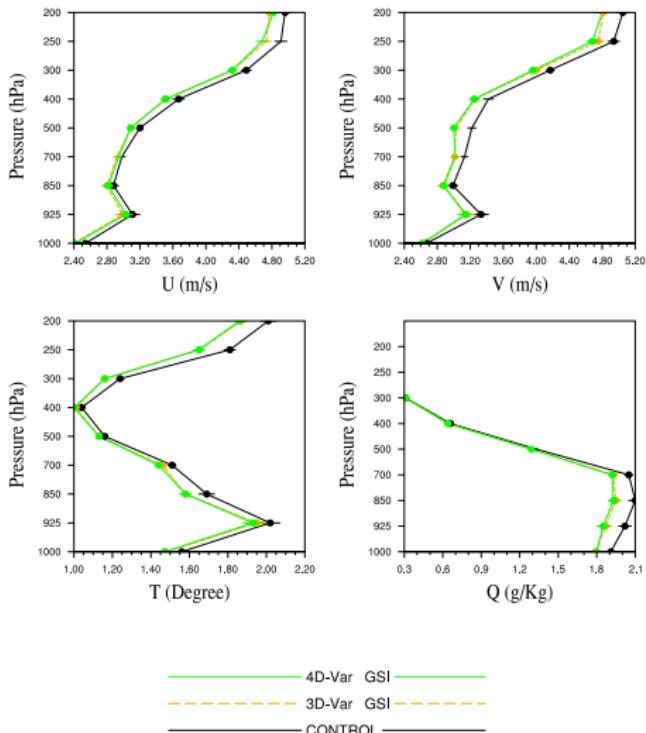
RMSE Verification—12h



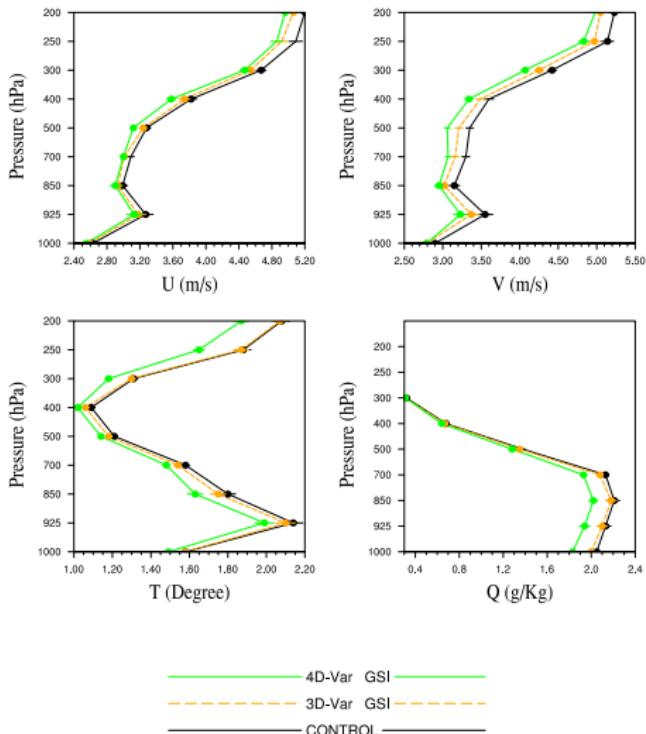
RMSE Verification—18h



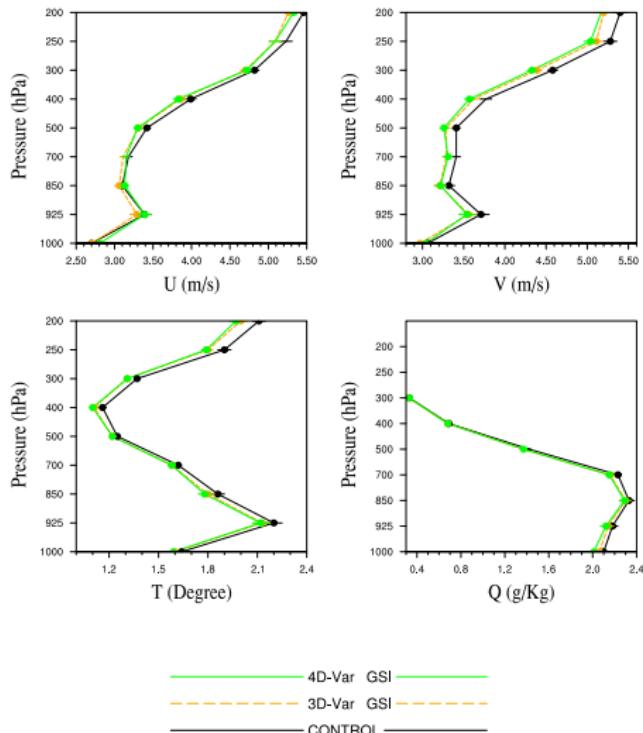
RMSE Verification—24h



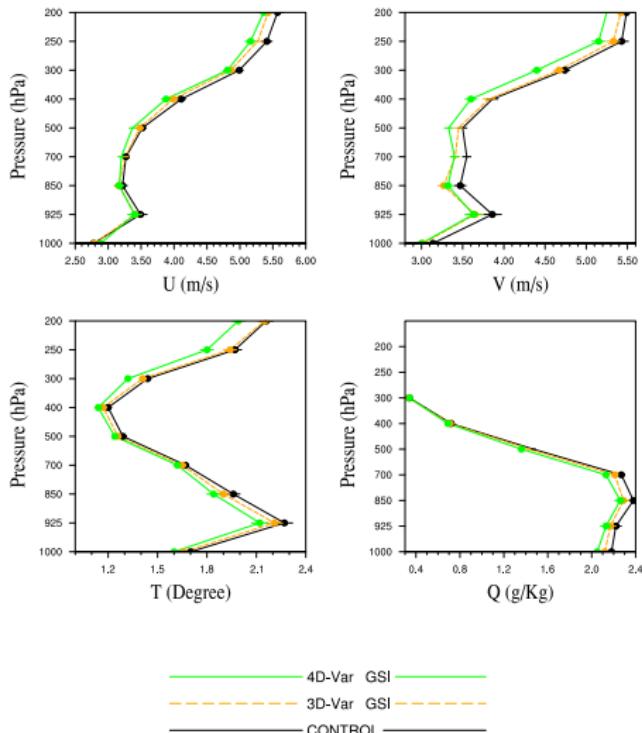
RMSE Verification—30h



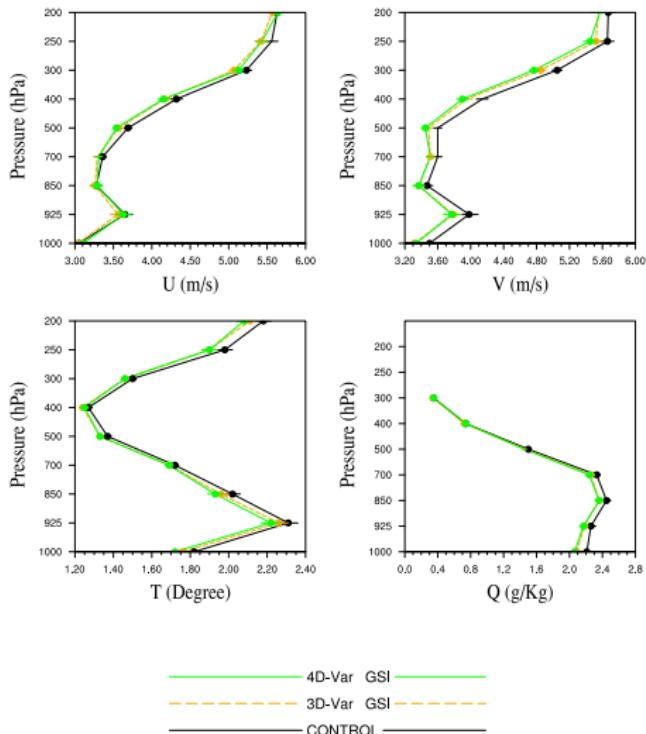
RMSE Verification—36h



RMSE Verification—42h



RMSE Verification—48h



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- The single observation exp. confirms that the system is valid and is able to produce flow dependent increments.
- The increments produced by 4D-Var run with tutorial case are comparable with the 3D-Var run.
- The real case shows the desirable performance of 4D-Var.



Latest achievements

- Implementation of the simplified physics packages into WRFPLUSV3 is done: surface drag(bl_pbl_physics=98), large scale condensation(mp_physics=98) and a simplified cumulus scheme(cu_physics=98).



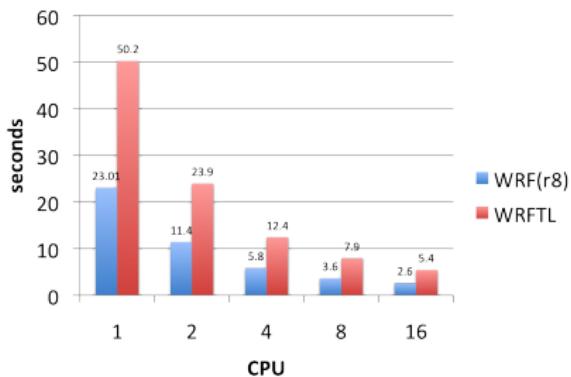
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One-time step timing

- 350x250x57L @27KM, time_step=150s
- Intel(R) Xeon(R) X7560 @ 2.27GHz
- 64G Memory
- 8 Processors , 8 cores/processor
- PGI 8.0-4 64-bit compiler.



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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