Development of regional GSI-based WRF 4D-Var

Xin Zhang      Xiang-Yu Huang

NCAR Earth System Laboratory

June 28 2011, GSI Workshop, Boulder, CO

NCAR is sponsored by the National Science Foundation
Outline

1. Introduction
2. WRFPLUS V3.3
3. Developments in GSI
4. GSI/WRF 4DVAR System Validation
   - Single observation exp. I
   - Single observation exp. II
   - Tutorial case
   - Real case
5. Summary
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.
- The WRF tangent linear and adjoint codes V3.3 (hereafter, WRFPLUS V3.3) has been re-written from scratch to be consistent with the latest WRF repository codes.
The development of GSI-based WRF 4D Var has been implemented in GSI Boulder’s version of May 2011.

The WRF tangent linear and adjoint codes V3.3 (hereafter, WRFPLUS V3.3) has been re-written from scratch to be consistent with the latest WRF repository codes.

The Major development in GSI had finished, GSI codes has been coupled with the WRF tangent linear and adjoint model.
The development of GSI-based WRF 4D Var has been implemented in GSI Boulder’s version of May 2011.

The WRF tangent linear and adjoint codes V3.3 (hereafter, WRFPLUS V3.3) has been re-written from scratch to be consistent with the latest WRF repository codes.

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.
The development of GSI-based WRF 4D Var has been implemented in GSI Boulder’s version of May 2011.

The WRF tangent linear and adjoint codes V3.3 (hereafter, WRFPLUS V3.3) has been re-written from scratch to be consistent with the latest WRF repository codes.

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.
Major Improvements of WRFPLUS V3.3

- Re-developed WRF adjoint and tangent linear codes from scratch based on the latest WRF repository codes.
- Testing the code on various platforms and compilers (IBM, Linux, Mac: xlf, g95, pgi, intel, gfortran).
Major Improvements of WRFPLUS V3.3

- Re-developed WRF adjoint and tangent linear codes from scratch based on the latest WRF repository codes.
- Testing the code on various platforms and compilers (IBM, Linux, Mac: xlf, g95, pgi, intel, gfortran).
- Adding capability to do tangent linear check and adjoint test over any length of time window.
Major Improvements of WRFPLUS V3.3

- Re-developed WRF adjoint and tangent linear codes from scratch based on the latest WRF repository codes.
- Testing the code on various platforms and compilers (IBM, Linux, Mac: xlf, g95, pgi, intel, gfortran).
- Adding capability to do tangent linear check and adjoint test over any length of time window.
- 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.
Major Improvements of WRFPLUS V3.3

- Re-developed WRF adjoint and tangent linear codes from scratch based on the latest WRF repository codes.
- Testing the code on various platforms and compilers (IBM, Linux, Mac: xlf, g95, pgi, intel, gfortran).
- Adding capability to do tangent linear check and adjoint test over any length of time window.
- 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.
Introduction

WRFPLUS V3.3
Developments in GSI
GSI/WRF 4DVAR System Validation

Summary

Sample 6h Tangent Linear and Adjoint Check

Taylor formula:

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

Tangent linear check

<table>
<thead>
<tr>
<th>alpha_m</th>
<th>coef</th>
<th>val_n</th>
<th>val_l</th>
</tr>
</thead>
<tbody>
<tr>
<td>.1000E+00</td>
<td>0.9825</td>
<td>0.3628649E+11</td>
<td>0.3693279E+11</td>
</tr>
<tr>
<td>.1000E-01</td>
<td>0.9978</td>
<td>0.3685192E+09</td>
<td>0.3693279E+09</td>
</tr>
<tr>
<td>.1000E-02</td>
<td>0.9994</td>
<td>0.3691401E+07</td>
<td>0.3693279E+07</td>
</tr>
<tr>
<td>.1000E-03</td>
<td>0.1000</td>
<td>0.3694225E+05</td>
<td>0.3693279E+05</td>
</tr>
<tr>
<td>.1000E-04</td>
<td>0.9981</td>
<td>0.3692603E+03</td>
<td>0.3693279E+03</td>
</tr>
<tr>
<td>.1000E-05</td>
<td>0.1000</td>
<td>0.3693638E+01</td>
<td>0.3693279E+01</td>
</tr>
<tr>
<td>.1000E-06</td>
<td>0.9999</td>
<td>0.3693154E-01</td>
<td>0.3693279E-01</td>
</tr>
<tr>
<td>.1000E-07</td>
<td>0.9999</td>
<td>0.3693279E-03</td>
<td>0.3693279E-03</td>
</tr>
<tr>
<td>.1000E-08</td>
<td>0.1000</td>
<td>0.3693285E-05</td>
<td>0.3693279E-05</td>
</tr>
<tr>
<td>.1000E-09</td>
<td>0.1000</td>
<td>0.3693288E-07</td>
<td>0.3693279E-07</td>
</tr>
<tr>
<td>.1000E-10</td>
<td>0.1000</td>
<td>0.3693446E-09</td>
<td>0.3693279E-09</td>
</tr>
</tbody>
</table>

Adjoint identity:

\[ \forall x, \forall y : \langle M', x, y \rangle = \langle x, M^*, y \rangle \]

Adjoint check

<table>
<thead>
<tr>
<th>ad_check:</th>
<th>VAL_TL:</th>
<th>0.424764898986911E+11</th>
</tr>
</thead>
<tbody>
<tr>
<td>ad_check:</td>
<td>VAL_AD:</td>
<td>0.424764898986912E+11</td>
</tr>
</tbody>
</table>
Modification in GSI

- Modified the capabilities to read and process multiple first guess and process obs. data for multiple time slots
- Added a new module which served as a coupler between GSI and WRFPLUS V3.3

WRF tangent linear and adjoint models are compiled as a library and callable subroutines. Added subroutine interfaces in model tl and model ad to call WRF tangent linear and adjoint model directly.

Zhang and Huang Development of regional GSI-based WRF 4D-Var
Modification in GSI

- Modified the capabilities to read and process multiple first guess and process obs. data for multiple time slots
- Added a new module which served as a coupler between GSI and WRFPLUS V3.3
- WRF tangent linear and adjoint models are compiled as a library and callable subroutines.
**Modification in GSI**

- Modified the capabilities to read and process multiple first guess and process obs. data for multiple time slots
- Added a new module which served as a coupler between GSI and WRFPLUS V3.3
- WRF tangent linear and adjoint models are compiled as a library and callable subroutines.
- Added subroutine interfaces in model_tl and model_ad to call WRF tangent linear and adjoint model directly.
Modification in GSI

- Modified the capabilities to read and process multiple first guess and process obs. data for multiple time slots.
- Added a new module which served as a coupler between GSI and WRFPLUS V3.3.
- WRF tangent linear and adjoint models are compiled as a library and callable subroutines.
- 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

- Modified the capabilities to read and process multiple first guess and process obs. data for multiple time slots
- Added a new module which served as a coupler between GSI and WRFPLUS V3.3
- WRF tangent linear and adjoint models are compiled as a library and callable subroutines.
- 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

- src/main/wrf_binary_interface.F90
- src/main/read_wrf_mass_files.f90
- src/main/control2model.f90
- src/main/update_guess.f90
- src/main/model_tl.F90
- src/main/control2state.f90
- src/main/model_ad.F90
- src/main/stub_pertmod.F90
- src/main/pcgsoi.f90
- src/main/adjtest.f90
- src/main/read_prepbufr.f90
- src/main/gsi_4dvar.f90
- src/main/wrf_pertmod.F90
- src/main/wrwrfmassa.F90
- src/main/wrf_netcdf_interface.F90
- src/main/gsimod.F90
- src/main/model2control.f90
- src/main/state2control.f90
- src/main/read_wrf_mass_guess.F90
- src/main/evaljgrad.f90
- src/main/Obsfile.dependency
- 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 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*

Delta T at 500 hPa
Height (m) at 500 hPa
Wind (kts) at 500 hPa

Height Contours: 5320 to 5880 by 80

Zhang and Huang

Development of regional GSI-based WRF 4D-Var
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

Total: 45040

Zhang and Huang

Development of regional GSI-based WRF 4D-Var
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
----------------Total-------------------
45040

Zhang and Huang
Cost functions and gradients – scaled by ALOG10

![Graphs showing cost functions and gradients for 3DVAR and 4DVAR methods.](image-url)
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)

4DVAR MU(1)

4DVAR QVAPOR(8)

Zhang and Huang
Development of regional GSI-based WRF 4D-Var
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

---

Zhang and Huang
Development of regional GSI-based WRF 4D-Var
RMSE Verification—06h

- Pressure (hPa) vs. U (m/s)
- Pressure (hPa) vs. V (m/s)
- Pressure (hPa) vs. T (Degree)
- Pressure (hPa) vs. Q (g/Kg)

Legend:
- **4D-Var GSI**
- **3D-Var GSI**
- **CONTROL**

Zhang and Huang

Development of regional GSI-based WRF 4D-Var
Development of regional GSI-based WRF 4D-Var

Zhang and Huang
RMSE Verification—18h

**Graphs:**
- U (m/s) vs. Pressure (hPa)
- V (m/s) vs. Pressure (hPa)
- T (Degree) vs. Pressure (hPa)
- Q (g/Kg) vs. Pressure (hPa)

**Legend:**
- 4D-Var GSI
- 3D-Var GSI
- CONTROL

**Table:**
- **Zhang and Huang**
- Development of regional GSI-based WRF 4D-Var
RMSE Verification—24h

- Single observation exp. I
- Single observation exp. II
- Tutorial case
- Real case

Zhang and Huang

Development of regional GSI-based WRF 4D-Var
RMSE Verification—30h

- **Single observation exp. I**
- **Single observation exp. II**
- **Tutorial case**
- **Real case**

Graphs showing comparison of different systems:
- **U (m/s)**
- **V (m/s)**
- **T (Degree)**
- **Q (g/Kg)**

Legend:
- 4D-Var GSI
- 3D-Var GSI
- CONTROL

Zhang and Huang

Development of regional GSI-based WRF 4D-Var
RMSE Verification—36h

- Single observation exp. I
- Single observation exp. II
- Tutorial case
- Real case

Graphs showing comparisons of pressure, wind speed, temperature, and specific humidity for different models and verification methods.
RMSE Verification—42h

Zhang and Huang

Development of regional GSI-based WRF 4D-Var
RMSE Verification—48h

- Single observation exp. I
- Single observation exp. II
- Tutorial case
- Real case

Zhang and Huang

Development of regional GSI-based WRF 4D-Var
Summary

- The basic GSI-based WRF 4D-Var system was developed.
- The single observation exp. confirms that the system is valid and is able to produce flow dependent increments.
The basic GSI-based WRF 4D-Var system was developed.

- 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 basic GSI-based WRF 4D-Var system was developed. 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.
The basic GSI-based WRF 4D-Var system was developed.
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).
- Parallelization of WRF tangent linear model is done.

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.
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).
- Parallelization of WRF tangent linear model is done.

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

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.

NCAR is sponsored by the National Science Foundation