WRF Four-dimensional variational data assimilation system Tutorial for V3.4

Xin Zhang, Xiang-Yu Huang, Jianyu Liu

NCAR Earth System Laboratory

Presented in July 2012, WRFDA Tutorial

NCAR is sponsored by the National Science Foundation

Pre-requirements to run WRF 4D-Var

- Knowledge and experience to run WRF model
- Knowledge and experience to run WRFDA (3D-Var)
- Knowledge and experience to run WRF 4D-Var V3.3

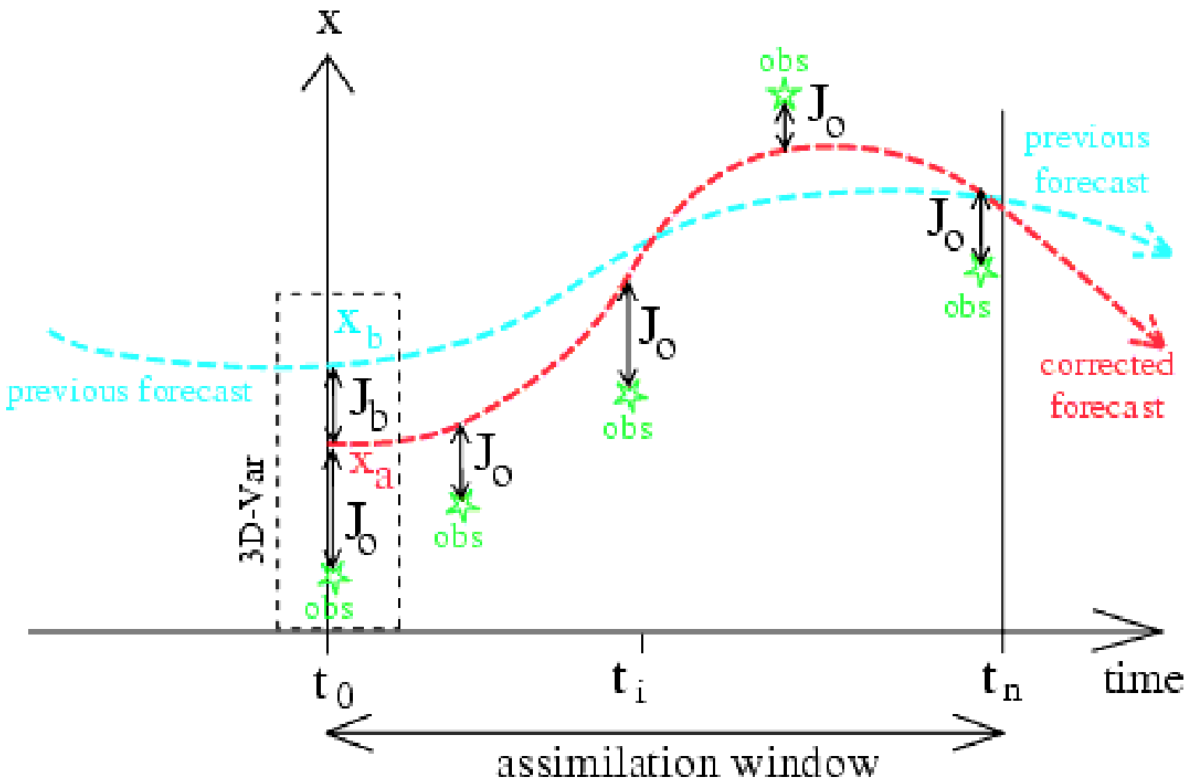
What's new in WRF 4D-Var V3.4

- WRFPLUS has been upgraded to V3.4 and it is consistent with the released WRF version 3.4
- 4D-Var system now supports compilation to run in parallel with distributed memory
- Precipitation data assimilation is now supported by the 4D-Var system
- Multi-incremental 4D-Var is supported

Developments after V3.4

- Continuing to optimize and evaluate the performance of the multi-incremental configuration, which allows resolution changes between innovation calculations and minimizations
- Revisiting the WRF tangent linear and adjoint codes related to tracer transportation for chemistry 4D-Var
- Finalizing the implementation of the tangent linear and adjoint codes of the GSFC short-wave radiation scheme to be used in future chemistry assimilation.

4D-Var versus 3D-Var



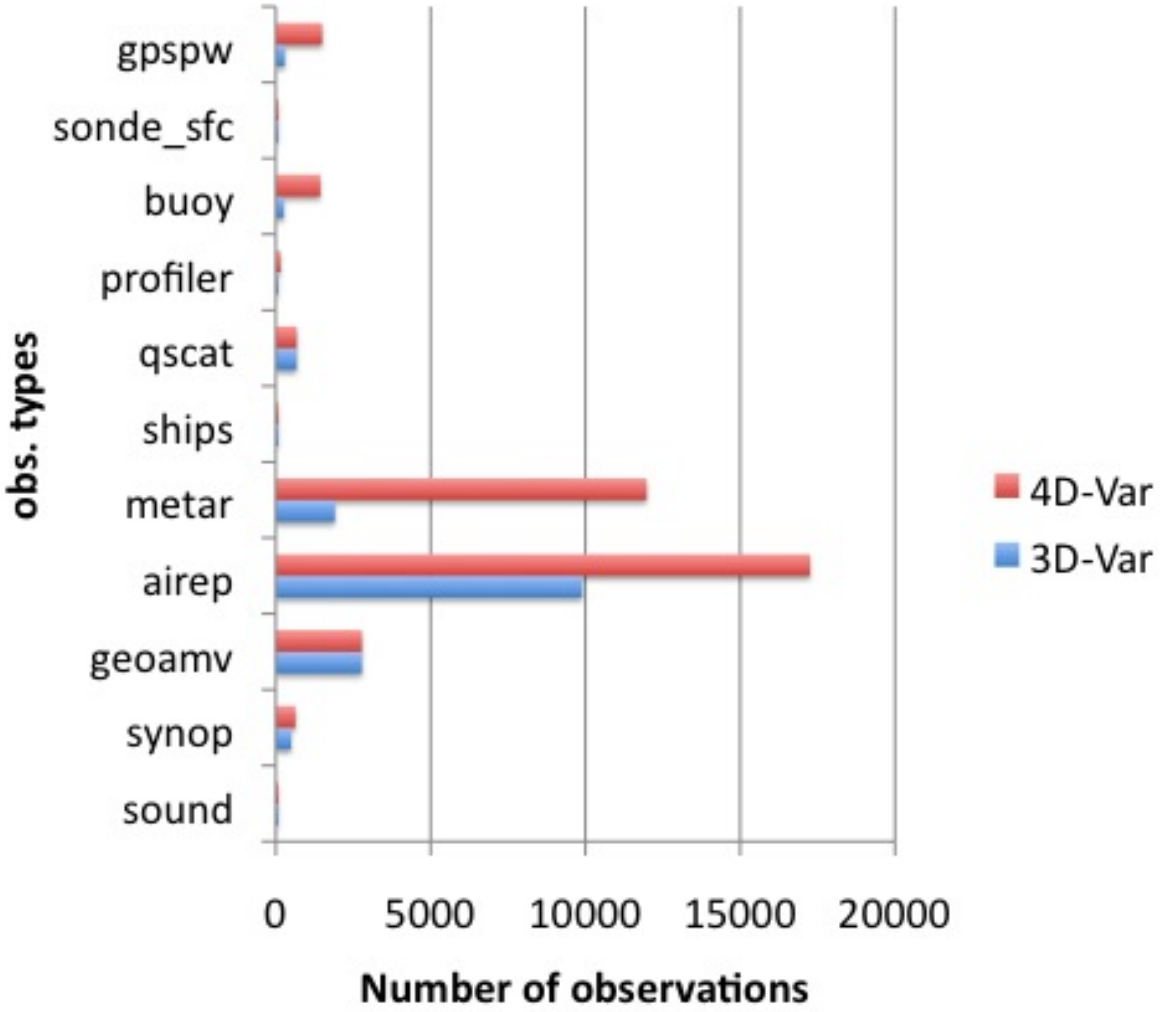
(Adopted from ECMWF training Course)

Advantage of 4D-Var

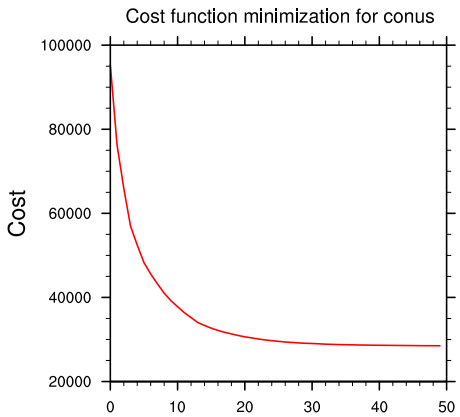
- 4D-Var is comparing observations with background model fields at the correct time
- 4D-Var can use observations from frequently reporting stations
- The dynamics and physics of the forecast model are an integral part of 4D-Var, so observations are used in a meteorologically more consistent way
- 4D-Var 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

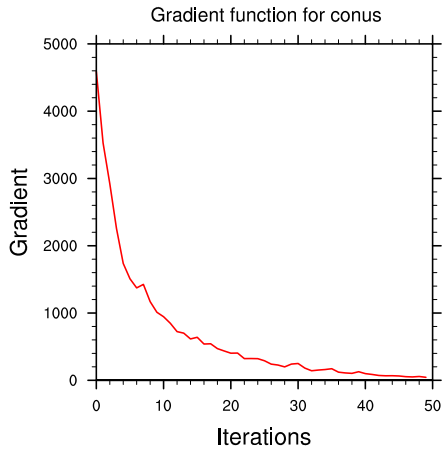
(Adopted from ECMWF training Course)

Comparison of obs. usage

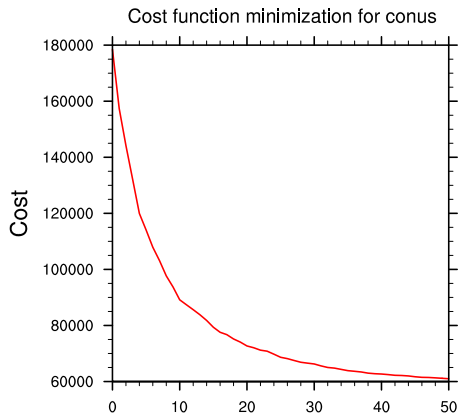


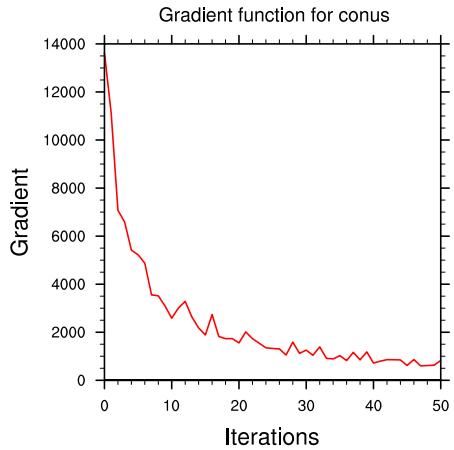
Minimization comparison





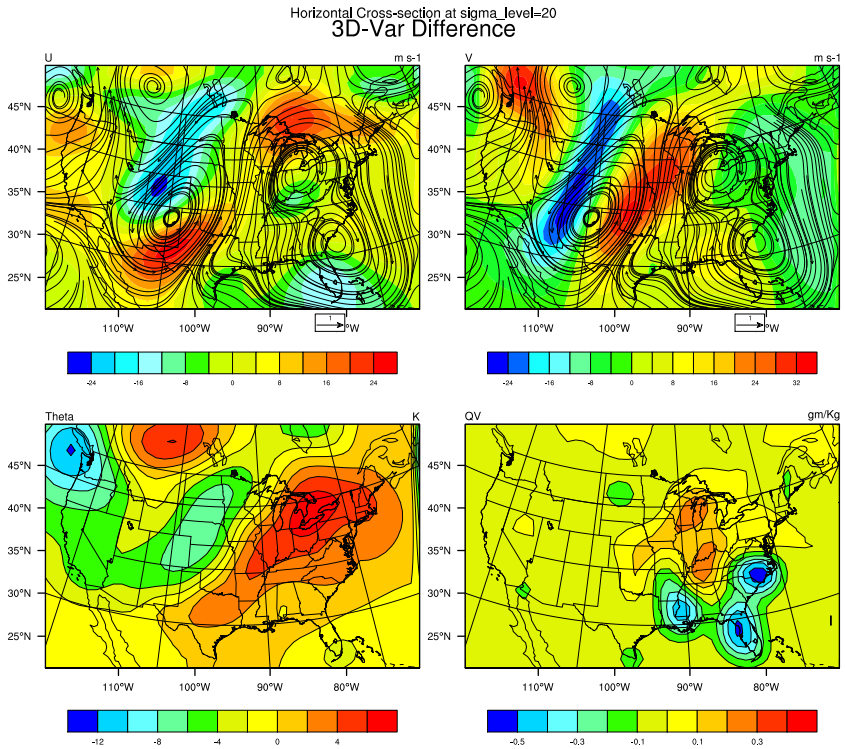
3D-Var

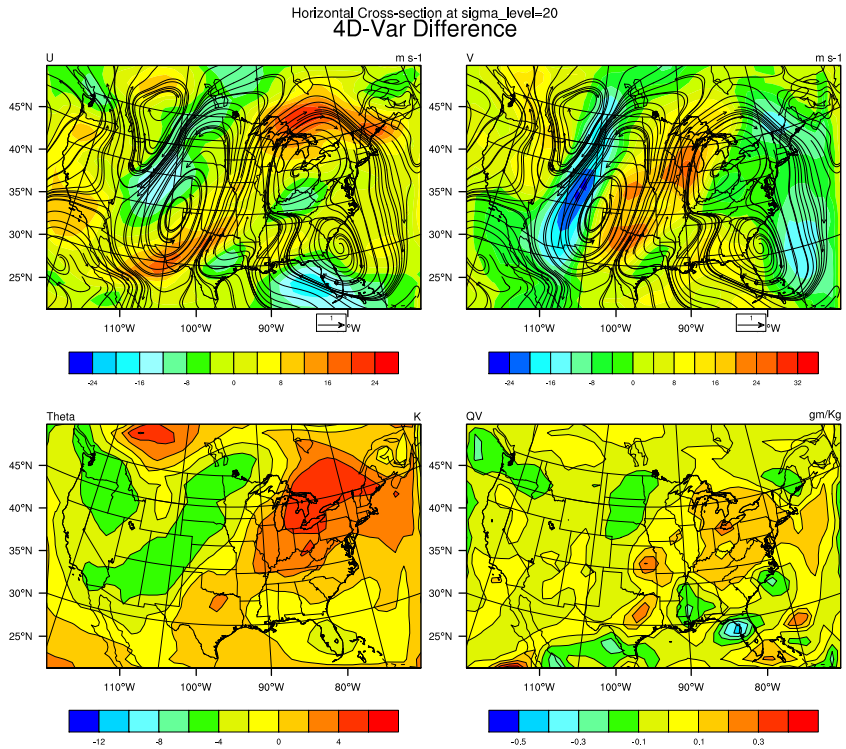




4D-Var

Sample analysis increments





Weak constraint with digital filter

$$J = J_b + J_o + J_c$$

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

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

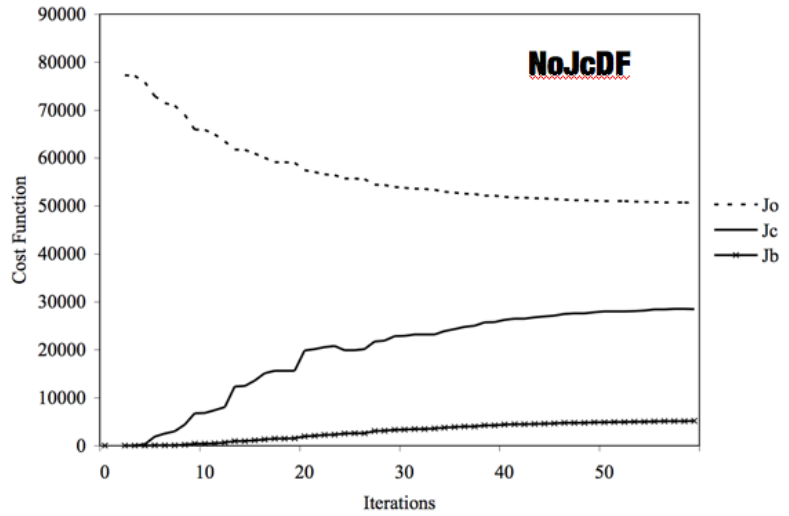
$$J_c(\mathbf{x}_0) = \frac{\gamma_{df}}{2}\left[\left(\delta\mathbf{x}_{N/2} - \delta\mathbf{x}^{df}_{N/2}\right)^T \mathbf{C}^{-1}\left(\delta\mathbf{x}_{N/2} - \delta\mathbf{x}^{df}_{N/2}\right)\right]$$

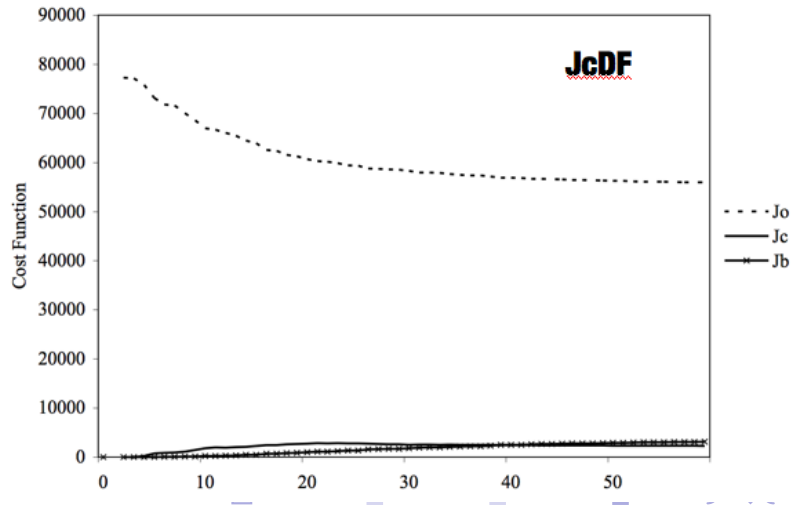
$$= \frac{\gamma_{df}}{2}\left[\left(\delta\mathbf{x}_{N/2} - \sum_{i=0}^{N} f_i\delta\mathbf{x}_i\right)^T \mathbf{C}^{-1}\left(\delta\mathbf{x}_{N/2} - \sum_{i=0}^{N} f_i\delta\mathbf{x}_i\right)\right]$$

$$= \frac{\gamma_{df}}{2}\left[\left(\sum_{i=0}^{N} h_i\delta\mathbf{x}_i\right)^T \mathbf{C}^{-1}\left(\sum_{i=0}^{N} h_i\delta\mathbf{x}_i\right)\right]$$

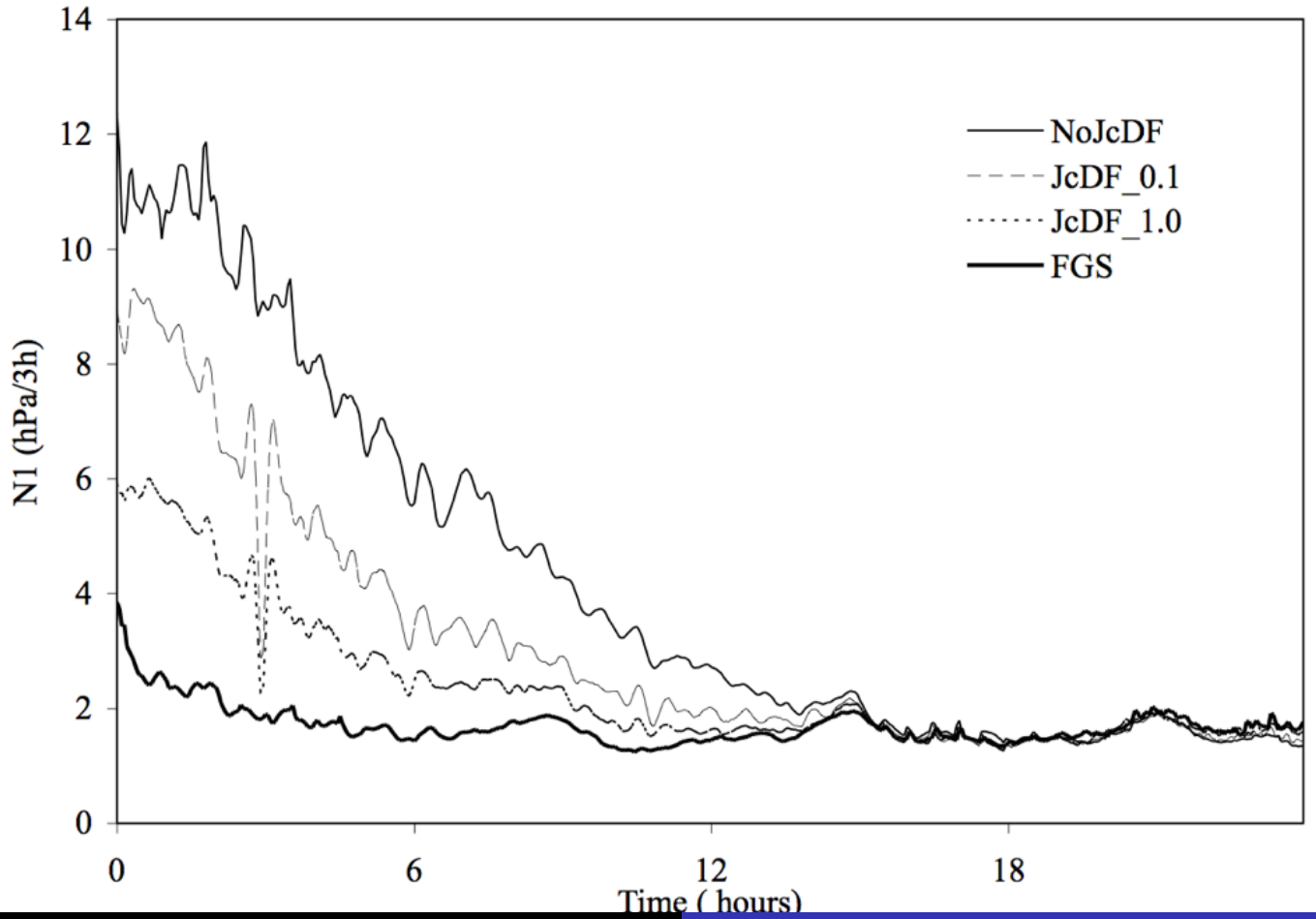
where:

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





Weak constraint with digital filter (domain averaged surface pressure variation)



Consider lateral boundary condition as control variable

$$J = J_b + J_o + J_c + J_{lbc}$$

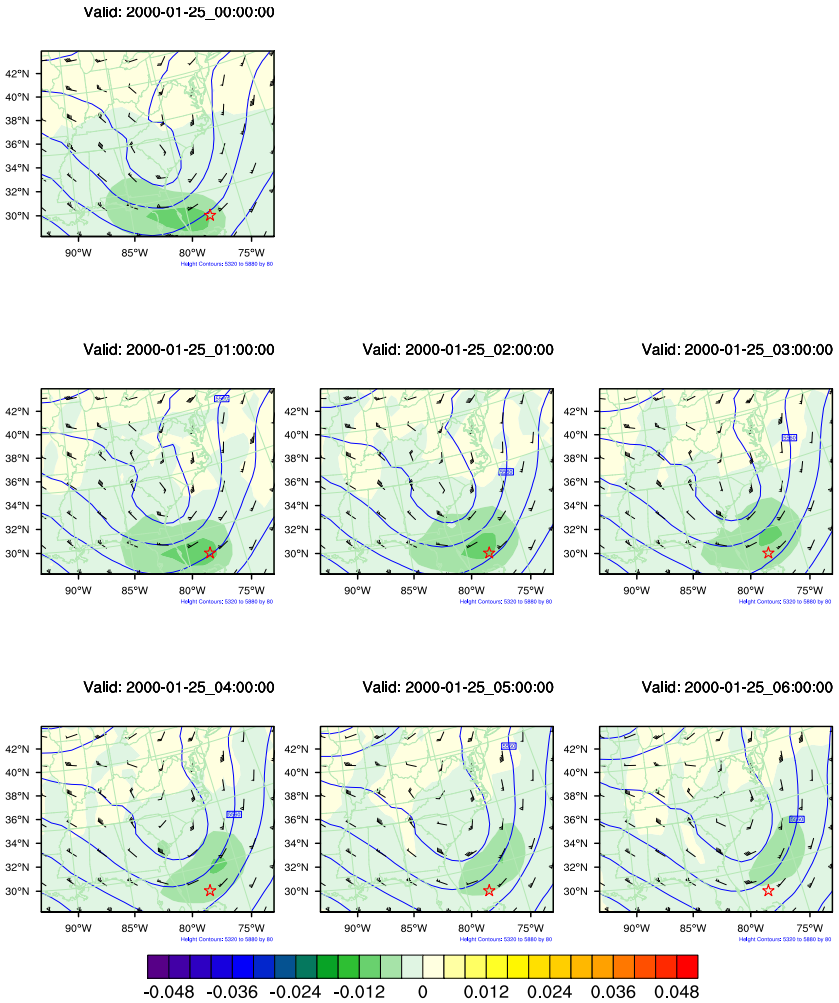
$$\begin{aligned} J_{lbc} &= \frac{1}{2}(\mathbf{x}(t_k) - \mathbf{x}_b(t_k))^T \mathbf{B}^{-1}(\mathbf{x}(t_k) - \mathbf{x}_b(t_k)) \\ &= \frac{1}{2}\delta\mathbf{x}(t_k)^T \mathbf{B}^{-1}\delta\mathbf{x}(t_k) \end{aligned}$$

J_{lbc} is the J_b at the end of the assimilation window lateral boundary control is obtained through

$$\frac{\partial \delta\mathbf{x}_{lbc}}{\partial t} = \frac{\delta\mathbf{x}(t_k) - \delta\mathbf{x}(t_0)}{t_k - t_0}$$

Single observation experiment

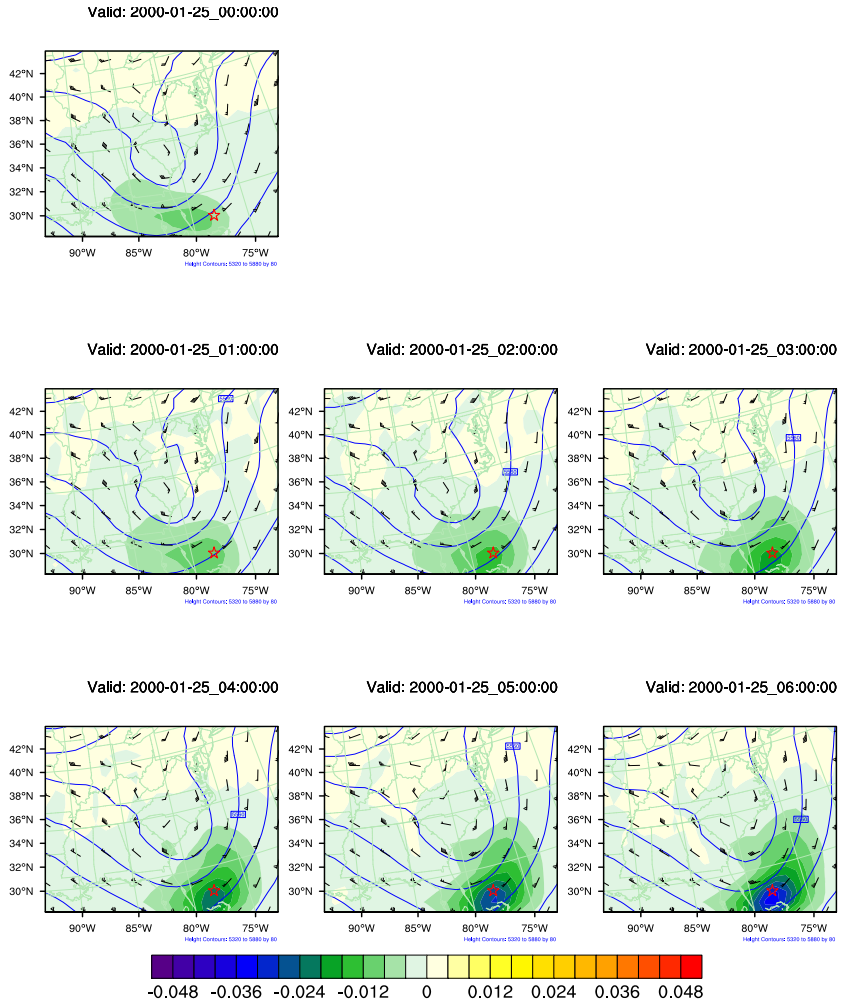
To investigate the impact of including boundary condition control in data assimilation, a 6h observation close to boundary is put at the downstream of the boundary inflow, we expect that the major analysis increments response at 0h should be in boundary condition and outside of the domain.



Remarks

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

- $\star$ is the location of obs. at the ending time (6h).
- $O - B = -0.95K$
- LBC control is turned off



Remarks

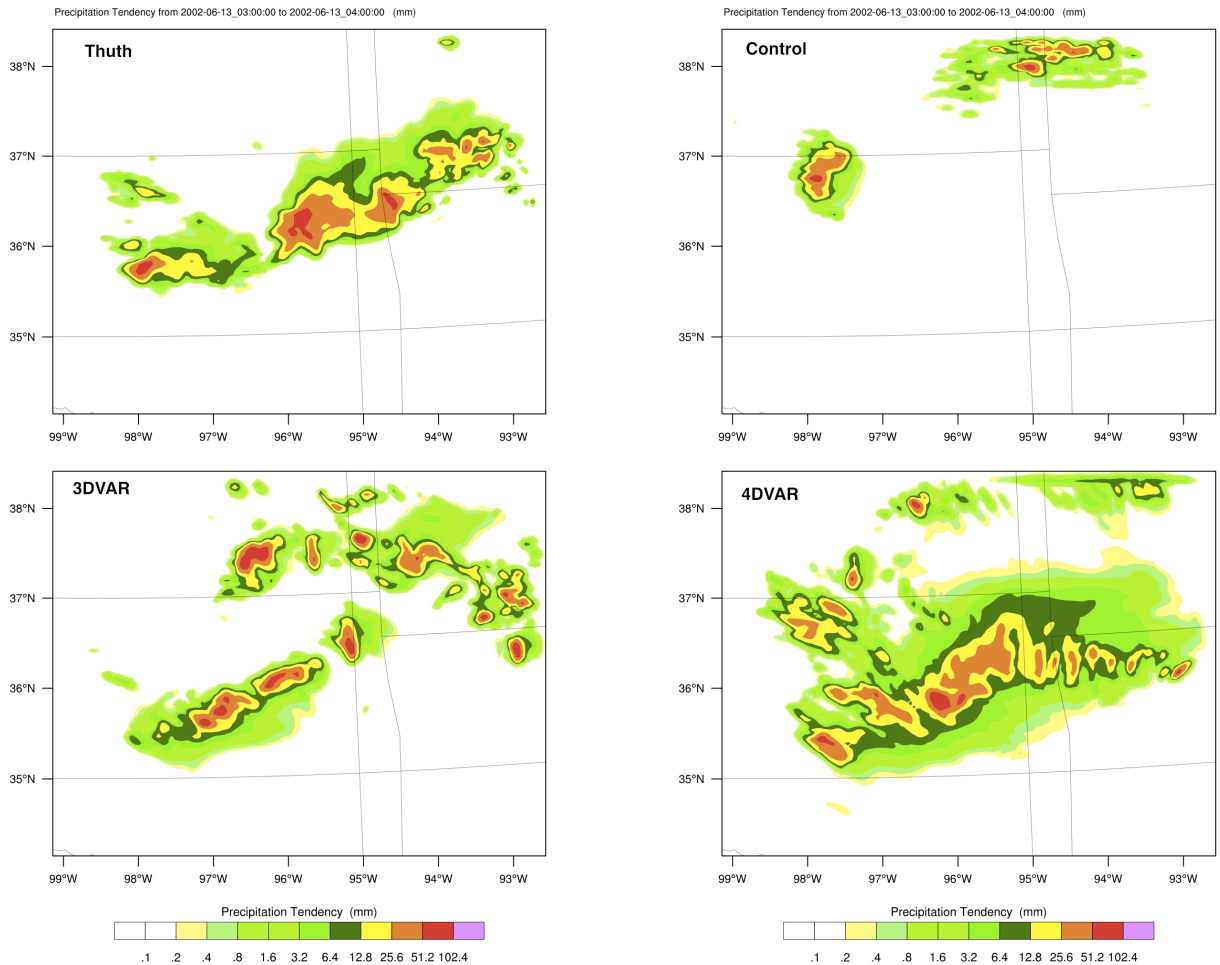
Forecasted 500mb T difference (DA forecast - reference forecast)

- ⋆ is the location of obs. at the ending time (6h).
- LBC control is turned on

An OSSE radar data assimilation with WRF 4D-Var

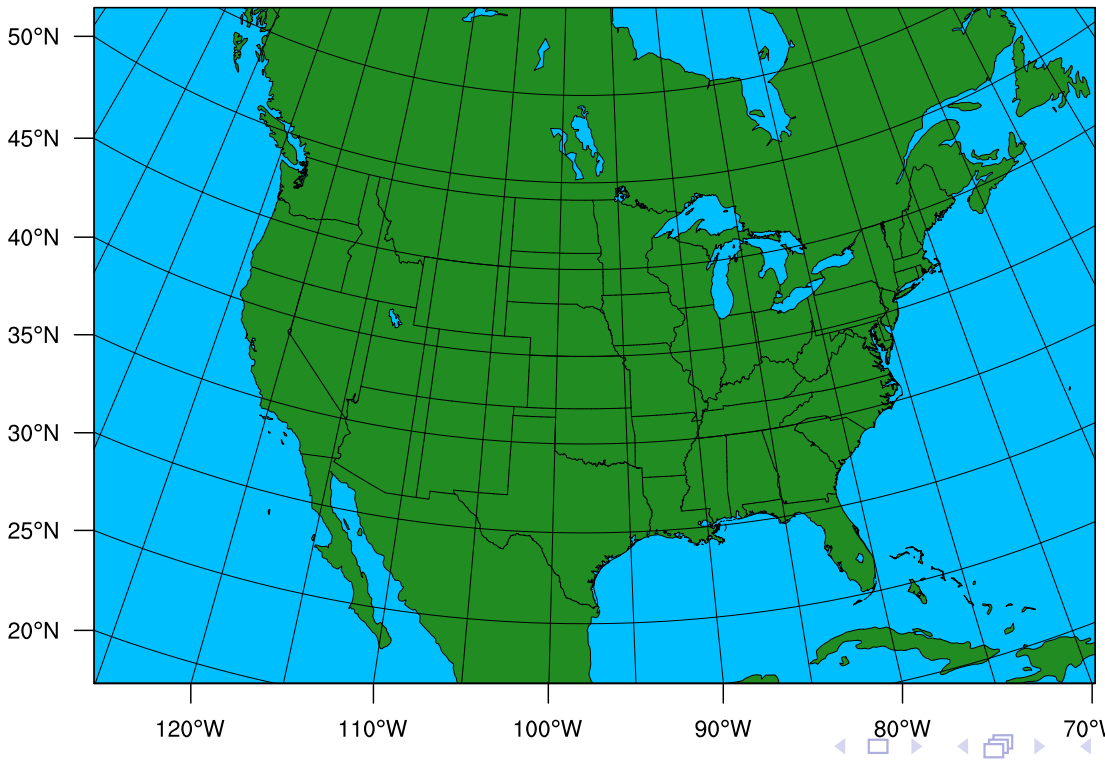
- TRUTH —– Initial condition from TRUTH (13-h forecast initialized at 2002061212Z from AWIPS 3-h analysis) run cut by ndown, boundary condition from NCEP GFS data.
- NODA —– Both initial condition and boundary condition from NCEP GFS data.
- 3DVAR ——3DVAR analysis at 2002061301Z used as the initial condition, and boundary condition from NCEP GFS. Only Radar radial velocity at 20 initial/boundary conditions 02061301Z assimilated (total data points = 97,033), 3 outer loops.
- 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 = 384,304), 3 outer loops.

OSSE 3rd hour precipitation simulation

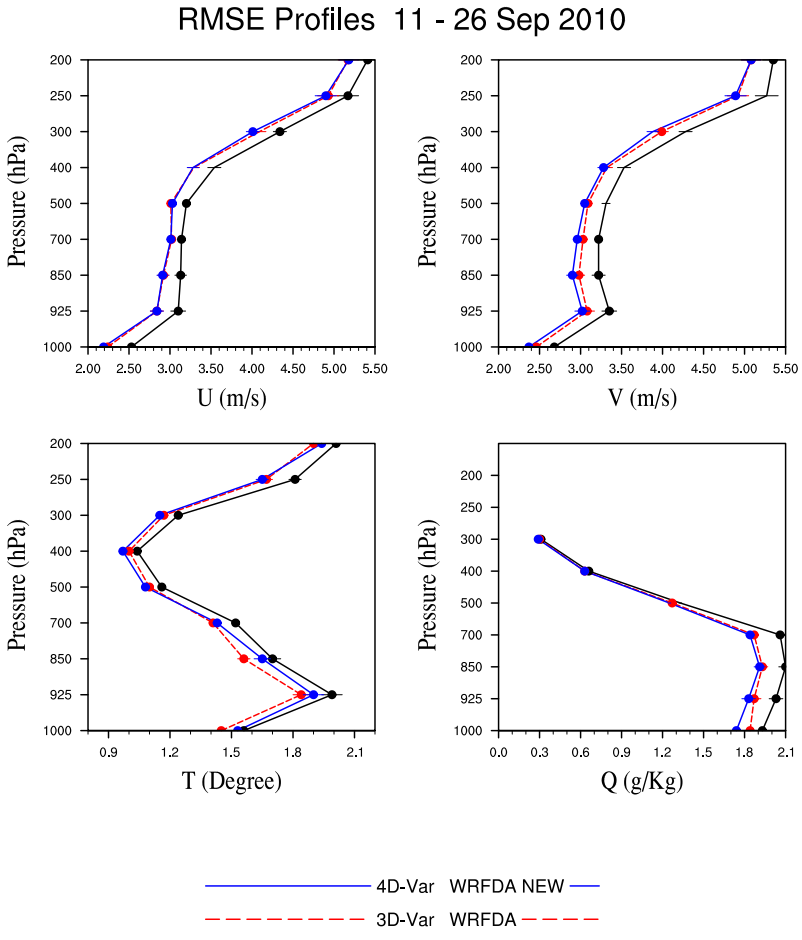


Experiment configuration

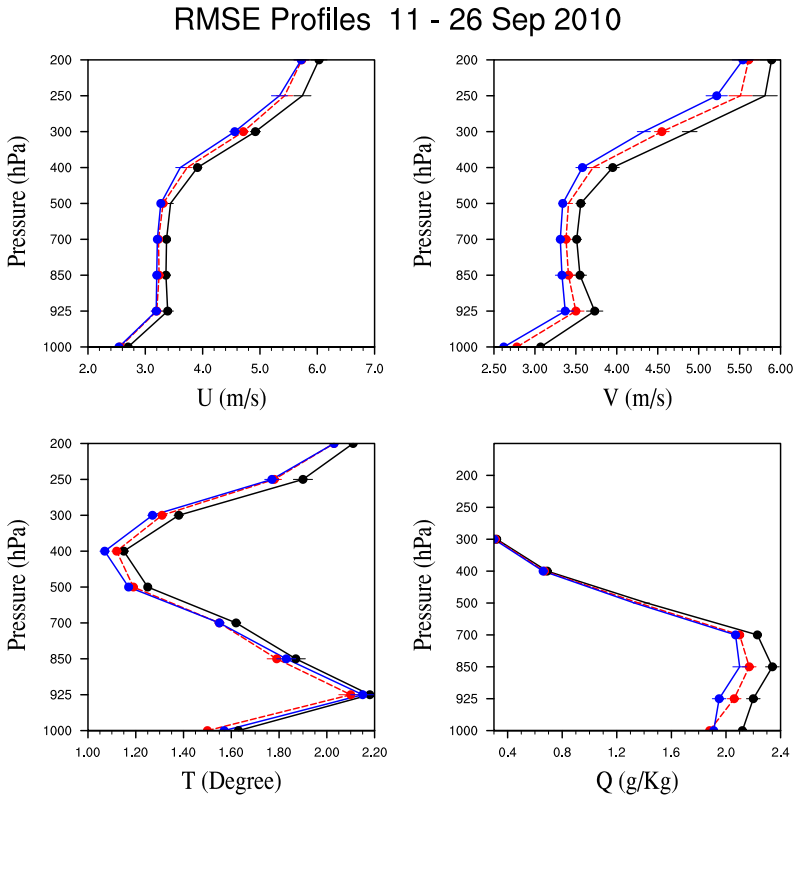
- Grids: 105x72x28L
- Resolution: 60km
- Period: 2010091100-2010092600 @0Z,6Z,12Z,18Z
- First guess is the 12h forecast from NCEP FNL
- 48h forecasts from FG, 3DVAR and 4DVAR
- Verified against NCEP GDAS prepbufr data



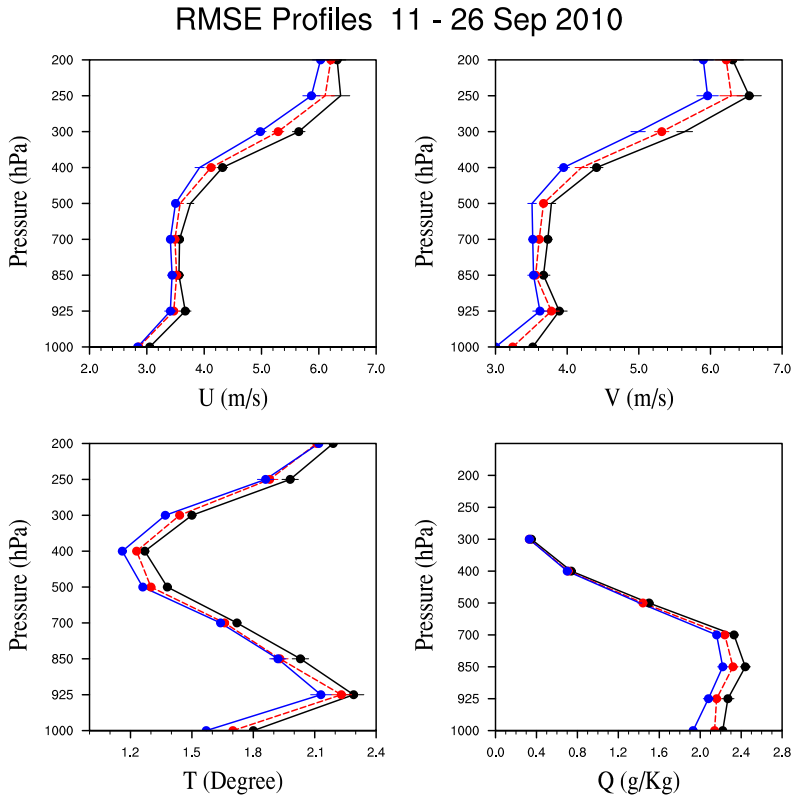
Averaged RMSE of 24H forecast verification



Averaged RMSE of 36H forecast verification



Averaged RMSE of 48H forecast verification



Get the source codes

- WRFDA codes :

  `http://www.mmm.ucar.edu/wrf/users/wrfda/download/get_source.html`

- WRFPLUSV3 codes and the patch:

  `http://www.mmm.ucar.edu/wrf/users/wrfda/download/wrfplus.html`

  `http://www.mmm.ucar.edu/wrf/users/wrfda/known-prob.html`

- Test Dataset :

  `http://www.mmm.ucar.edu/wrf/users/wrfda/download/WRFDAV3.4-testdata.tar.gz`

Installation

- Install WRFPLUS V3.4
  - *./configure (−d) wrfplus*
  - *./compile em_real*
  - *wrf.exe* should be generated under *main* directory.
- Install WRFDA 4D-Var V3.4
  - for csh, tcsh : *setenv WRFPLUS_DIR path_of_wrfplusv3*
  - for bash, ksh : *export WRFPLUS_DIR = path_of_wrfplusv3*
  - *./configure (−d) 4dvar*
  - *./compile all_wrfvar*
  - *da_wrfvar.exe* should be generated under *var/build* directory.

Tips for compilation

- Speed up the compilation with parallel make — gnu make only
  setenv J "-j 6"
- Assimilate prepbufr observation :
  csh, tcsh : *setenv BUFR 1*
  bash, ksh : *export BUFR = 1*
- Assimilate radiance bufr data with CRTM :
  csh, tcsh : *setenv CRTM 1*
  bash, ksh : *export CRTM = 1*
- Assimilate radiance bufr data with RTTOV :
  csh, tcsh : *setenv RTTOV /your/path/of/rttov*
  bash, ksh : *export RTTOV = /your/path/of/rttov*

comments

These environment variables need to be set before running the configure script

Portability

We have tested the WRF 4D-Var V3.4 on following systems:

- IBM with XLF compiler V13.0
- Linux with PGI compiler V8.0-4
- Linux with INTEL compiler V12.0
- Linux with GFORTRAN compiler V4.4.0
- Mac with PGI compiler V10.3-0
- Mac with INTEL compiler V11.1
- Mac with GFORTRAN compiler V4.4.0
- Mac with G95 compiler V0.92

Common problems in compilation

- Enough memory is needed to compile some subroutines in WRFPLUS with default optimization level (-O3). Manually reduce the compilation optimization level for some subroutines when system can not allocate enough memory to perform compilation with higher level optimization.
- If compilers doesn't support to compile with real_size=8. Usually, upgrading the compiler is the easiest way to solve this problem.

Test for tangent linear model and adjoint model

- After WRFPLUS compilation, it is a good practice to run tangent linear model test and adjoint model test with you own case's IC and BC.
- Under *WRFPLUSV3/test/em_real* directory, a test case is set up to let users test the tangent linear model and adjoint model.
- In *namelist.input*, turn on *check_TL* and/or *check_AD* in *&perturbation* to run tangent linear check or adjoint check.

Test for tangent linear model

$$\lim_{\alpha \to 0} \frac{||\mathcal{M}(\mathbf{x} + \alpha\delta\mathbf{x}) - \mathcal{M}(\mathbf{x})||_2}{||\mathbf{M}(\alpha\delta\mathbf{x})||_2} = 1$$

check results

```
 =============== Tangent Linear check ==================
 check==== U === V === W == PH === T == MU == MOIST =====
 check     T     T     T     T     T     T     T
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
```

Test for adjoint model

adjoint identity:

$$\forall \mathbf{x}, \forall \mathbf{y} : \langle \mathbf{M}\mathbf{x}, \mathbf{y} \rangle = \langle \mathbf{x}, \mathbf{M}^T \mathbf{y} \rangle$$

check results

```
ad_check: VAL_TL:     0.41466174569087E+11
ad_check: VAL_AD:     0.41466174569088E+11
```

- The tangent linear model might be imperfect.
- The adjoint test must be perfect, otherwise, there are bugs in the adjoint model.

Adjoint check for 4D-Var

It is always a good practice to run the adjoint check before the product run. How:

- `&wrfvar10`
  `test_transforms=true,`
- run

  `da_wrfvar.exe`

Check results

```
...
 wrf: back from adjoint integrate
 d01 2008-02-05_21:00:00 read nonlinear xtraj time stamp:2008-02-05_21:00:00
 Single Domain < y, y     > =   2.15435506772433E+06
 Single Domain < x, x_adj > =   2.15435506772431E+06

 Whole Domain < y, y     > =   2.15435506772433E+06
 Whole Domain < x, x_adj > =   2.15435506772431E+06

da_check_xtoy_adjoint: Test Finished:

 *** WRF-Var check completed successfully ***
```

Answers to frequently asked questions regarding to WRFPLUS

- WRFPLUS only works with regional ARW core, not for NMM core or global WRF.
- WRFPLUS only works with single domain, not for nested domains.
- WRFPLUS can not work with Adaptive Time Stepping options.
- WRFPLUS only has three simplified physics processes: surface drag (bl_pbl_physics=9); large scale condensate (mp_physics=98); a simplified cumulus scheme (cu_physics=98)

WRF 4D-Var observations preparation

- Conventional observations — LITTLE_R format

  `http://www.mmm.ucar.edu/wrf/users/wrfda/Tutorials/2012_July/docs/WRFDA_obsproc.pdf`

- OR Conventional observations — prepbufr format
  - near real-time data : `ftp://ftp.ncep.noaa.gov/pub/data/nccf/com/gfs/prod`
  - history archives : `http://dss.ucar.edu/dataset/ds337.0`
- Satellite radiance bufr data
  - near real-time data : `ftp://ftp.ncep.noaa.gov/pub/data/nccf/com/gfs/prod`
  - history archives : `http://dss.ucar.edu/dataset/ds735.0`
- Ascii-formatted Radar data

  `http://www.mmm.ucar.edu/wrf/users/wrfda/Tutorials/2012_July/docs/WRFDA_radar.pdf`

Tips for using prepbufr and bufr data on non-IBM platforms

On non-IBM platforms, the prepbufr- and bufr-format observations downloaded from NCEP ftp server or NCAR achives should be converted. This conversion was conducted using the C code ssrc.c located in the *utils* directory of the GSI distribution.

For more detailed information and GSI codes download, please refer to

`http://www.dtcenter.org/com-GSI/users/support/faqs/index.php`

- How to compile ssrc.c:

  pgcc -o ssrc.exe ssrc.c

- How to convert :

  ssrc.exe < prepbufr.gdas.2008020600.wo40 > ob.bufr

  ssrc.exe < gdas.1bamua.t00z.20080206.bufr > amusa.bufr

Important namelist variables for 4D-Var run

- *&wrfvar1*
  - *var4d*: logical, if running 4D-Var
  - *var4d_lbc* : logical, if including lateral boundary condition control in 4D-Var
  - *var4d_bin*: integer, seconds, length of sub-window to group observations in 4D-Var
- *&perturbation*
  - *trajectory_io*: logical, do not change, for testing purpose
  - *enable_identity* : logical, if running TL/AD model with identity model, testing purpose
  - *jcdfi_use*: logical, if turn on the digital filter as a weak constraint.
  - *jcdfi_diag*: integer, 0/1, J_c term diagnostics
  - *jcdfi_penalty*: real, weight to jcdf term

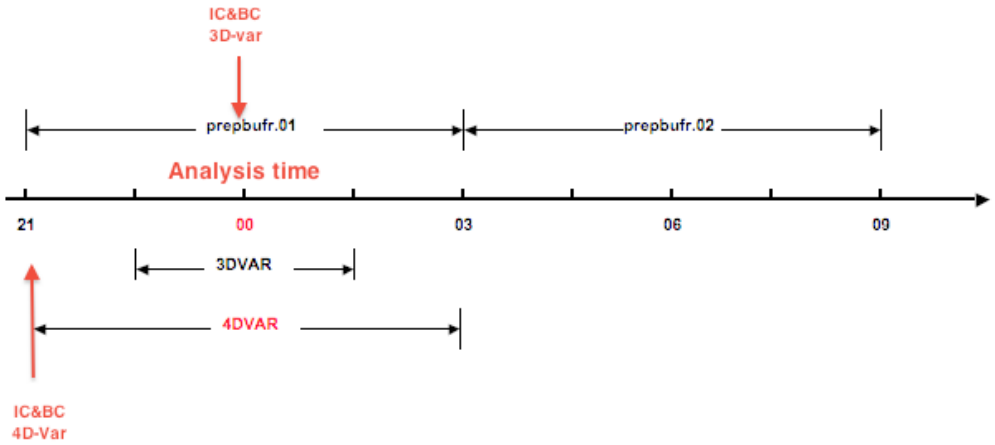
Important namelist variables for 4D-Var run, cont'd

- *&physics*
  - all physics options must be consistent with those used in wrfinput or fg
- *&wrfvar*18, 21, 22
  - *analysis_date* is the start time of the assimilation window
  - *time_window_min* is the start time of the assimilation window
  - *time_window_max* is the end time of the assimilation window
- *&time_control*
  - *run_xxxx* must be consistent with the length of the assimilation window
  - *start_xxxx* must be consistent with the start time of the assimilation window
  - *end_xxxx* must be consistent with the end time of the assimilation window

Tips for 4D-Var namelist settings

- *var4d_bin* must be divisible by time_step (*&domain*) exactly
- *interval_seconds* (*&time_control*) must be consistent with the length of the assimilation window
- Use wrfinput and wrfbdy files from earlier WRF V3 versions only if one sets hypsometric_opt = 1 in namelist &domains.

Symmetric 4D-Var window



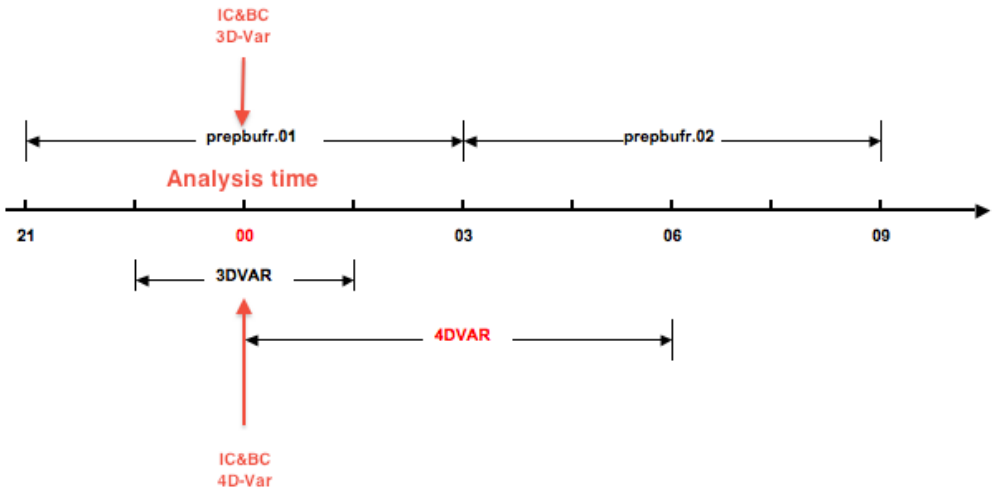
bufr/prepbufr observations need to be linked

link/copy prepbufr data at 00Z as $ob01.bufr$

Generate IC and BC

- Hybrid time trajectory (18Z + 00Z)
- Single time trajectory (18Z)

One-side 4D-Var window



bufr/prepbufr observations needs to be linked

link/copy prepbufr data at 00Z as $ob01.bufr$
link/copy prepbufr data at 06Z as $ob02.bufr$

Link run-time parameter files

```
ln -sf /your/be                    be.dat
ln -sf WRFDA/run/LANDUSE.TBL       LANDUSE.TBL

ln -sf WRFDA/run/RRTM_DATA_DBL     RRTM_DATA
ln -sf WRFDA/run/SOILPARM.TBL      SOILPARM.TBL
ln -sf WRFDA/run/GENPARM.TBL       GENPARM.TBL
ln -sf WRFDA/run/VEGPARM.TBL       VEGPARM.TBL
ln -sf WRFDA/run/URBPARM.TBL       URBPARM.TBL
```

Link IC and BC

```
ln -sf /your/1st/firstguess    fg
ln -sf /your/2nd/firstguess   fg02
ln -sf /your/boundary   wrfbdy_d01
ln -sf fg wrfinput_d1
```

Comments

- fg02 is only needed when var4d_lbc = .true.
- To generate 2nd firstguess only
  - set start and end times at the end of the assimilation window in namelist
  - re-run real.exe (make sure to rename the 1st wrfinput before re-running real)

Assimilate satellite radiance data

Refer to WRFDA Users' guide Chapter 6:

http://www.mmm.ucar.edu/wrf/users/wrfda/Docs/user_guide_V3.4/users_guide_chap6.htm#_Radiance_Data_Assimilations

namelist.input for radiance data :

```
&wrfvar4
use_amsuaobs=true,
use_amsubobs=true,
&wrfvar14
rtminit_nsensor=6,
rtminit_platform=1,1,1,1,1,1,
rtminit_satid=15,16,18,15,16,17,
rtminit_sensor=3,3,3,4,4,4,
thinning_mesh=120.0,120.0,120.0,120.0,120.0,120.0,
thinning=true,
qc_rad=true,
rtm_option=2,
use_varbc=true,
use_crtm_kmatrix=true,
```

Links for radiance assimilation

- For One-Side Window
  link/copy amsua data at 00Z as $amsua01.bufr$
  link/copy amsua data at 06Z as $amsua02.bufr$
  link/copy ...
- Symmetric Window
  link/copy amsua data at 00Z as $amsua01.bufr$
  link/copy ...
- $ln -fs\ WRFDA/var/run/VARBC.in\ VARBC.in$
- $ln -fs\ WRFDA/var/run/radiance\_info\ radiance\_info$
- $ln -fs\ WRFDA/var/run/crtm\_coeffs\ crtm\_coeffs$ (For CRTM)
  OR
  $ln -fs\ /your/rttov/path/rtcoef\_rttov10/rttov7pred51L\ rttov\_coeffs$ (For RTTOV)

- CRTM already bundled with WRFDA
- RTTOV needs to download and build separately before building WRFDA with it (`http://research.metoffice.gov.uk/research/interproj/nwpsaf/rtm/`)

Assimilate Precipitation data

Refer to WRFDA Users' guide Chapter 6:

`http://www.mmm.ucar.edu/wrf/users/wrfda/Docs/user_guide_V3.4/users_guide_chap6.htm#Precipitation`

namelist for precipitation data

- &*wrfvar*1
  - *var4d_bin_rain*: integer, seconds, precipitation observation sub-window length for 4D-Var
- &*wrfvar*4
  - *use_rainobs*: logical, true for assimilating precipitation
  - *thin_rainobs*: logical, true for performing thinning
  - *thin_mesh_conv*: integer, specifies thinning mesh size in km

Assimilate Precipitation data, cont'd

Precipitation Data Format

```
TOTAL = 987601,MISS. =-888888.,
INFO  = PLATFORM, DATE, LEVELS, LATITUDE, LONGITUDE, ELEVATION, ID.
EACH  = HEIGHT, RAINFALL DATA, QC, ERROR
#------------------------------------------------------------------------------#
FM-129 RAIN  2008-02-05_17:59:59      1      23.117      -119.022 -88888.0 xxxxx
 -888888.000      12.100  88       2.000
FM-129 RAIN  2008-02-05_17:59:59      1      23.125      -118.988 -88888.0 xxxxx
 -888888.000       8.000  88       2.000
FM-129 RAIN  2008-02-05_17:59:59      1      23.132      -118.955 -88888.0 xxxxx
 -888888.000 -888888.000  88       2.000
```

Format of data section

```
FMT_INFO = '(A12, 1X, A19, 1X, I6, 2(F12.3,2X), F8.1, 1X, A5)'
FMT_EACH = '(F12.3, F12.3, I4, F12.3)'
```

Tools for NCEP Stage IV gauge precipitation data

```
http://www.mmm.ucar.edu/wrf/users/wrfda/download/CONVERTER.gz
```

Assimilate Precipitation data, cont'd

```
Precipitation data is linked as obXX.rain.  XX is assigned by this rule:
                X=i*(var4d_bin_rain/var4d_bin)+1
here, i is the serial number of observations, a prefix '0' should be padded if X<10

For example, there are two observations, ob.rain.2008020515.03h and ob.rain.2008020518.03h.
var4d_bin=3600,
var4d_bin_rain=10800,
ob.rain.2008020515.03h (i=1) should be linked to ob04.rain
ob.rain.2008020518.03h (i=2) should be linked to ob07.rain.
```

- The QC flags referenced from OBSPROC QC classification, leave it as 88 if no particular reason
- Height and elevation are just used as the storage and preserved for future, not the actual data as the fields name.
- The type of precipitation is defined by *var4d_bin_rain*, there is NO flags to state the window length of cumulative precipitations in the file
- It should take obXX.rain as an alias of time slots and only use as a link
- It's better to use a meaningful filename for the precipitation data
- If *var4d_bin_rain* didn't match the type of precipitation, codes will still work, and this issue is not easy to be detected.

Multi-incremental 4D-Var

- Why use Multi-incremental 4D-Var

  It's an economical implementation for operation

- How it works
  - Calculate innovation on high resolution fg (stage1)
  - Do minimization on low resolution fg (stage2)
  - Regrid the incremental to high resolution fg

- BE

  Multi-incremental run only needs the low resolution BE (for CV5)

- General rules for running Multi-incremental 4D-Var

```
Step 1: Set multi_inc=1(&wrfvar1) in namelist.input
Run da_wrfvar.exe on high resolution fg
Step 2: Set multi_inc=2(&wrfvar1)
Switch to low resolution fg and run da_wrfvar.exe
Step 3: Get the incremental (difference of wrfvar_output and fg)
and re-grid it to high resolution fg
```

Tips for Multi-incremental 4D-Var

- It's necessary to clean all of innovation files (gts_omb.XXX.*) before re-running the same case
- Multi-incremental 4D-Var doesn't support multi-outerloops (max_ext_its>1). It will be supported in next releasing
- To run Multi-incremental 4D-Var with the general rules, it needs to generate two sets of fg and bdy, and write your own incremental re-gridding mods.
- The WRF data assimilation development team has developed a set of tools to simplify the whole procedure for multi-incremental 4DVAR for internal use only. Due to very limited resources being funded for support, we can not provide support to these tools, use them at your own risk. It can be downloaded from the WRFDA users page at

```
http://www.mmm.ucar.edu/wrf/users/wrfda/download/multi_inc_tools.tar.gz
```

Wall Clock of Multi-incremental 4D-Var

CPU : Intel(R) Xeon(R) CPU X7560 @ 2.27GHz
Fine grids : 121 X 91 @ 30km, 45 levels, top 50hPa
Coarse grids : 41 X 31 @ 90km, 45 levels, top 50hPa

- Multi-incremental 4D-Var (16 cores) : about 20mins
  - innovation : 2 mins
  - minimization : 18 mins
- Full resolution 4D-Var (32 cores): about 4Hrs

Update BC

Refer to WRFDA Users guide Chapter 6:

http://www.mmm.ucar.edu/wrf/users/wrfda/Docs/user_guide_V3.4/users_guide_chap6.htm#_Updating_WRF_lateral_1

```
&control_param
 da_file = 'wrfvar_output'
 da_file_02 = 'ana02'
 wrf_bdy_file = 'wrfbdy_d01'
 wrf_input = 'wrfinput_d01'
 domain_id = 1
 var4d_lbc = .true.
 debug = .false.
 update_lateral_bdy = .true.
 update_low_bdy = .false.
 update_lsm = .false.
/
```

- It is same as 3DVAR if var4d_lbc = .false.
- ana02 is only available when var4d_lbc = .true., and it will update the 1st and 2nd time level of boundary
- It doesn't check time information, just simply update the 1st time level of boundary, and the 2nd time level of boundary (4D-Var only)

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