WRFDA-3DVar Setup, Run, and Diagnostics

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Outline

- Installing WRFDA-3DVar
- Setting-up a WRFDA-3DVar run (namelist configurations)
- Making a WRFDA-3DVar run
- Running UPDATE_BC
- WRFDA-3DVar diagnostics

This presentation is based on WRFDA V3.6

Installing WRFDA-3DVar

Source Code

- Download WRFDA source code (WRFDA_V3.6.tar.gz) from

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

FORTRAN 90 Compilers

Supported and tested platforms:

- IBM with XLF compiler V13.0
- Linux with INTEL compiler V12.1.5+
- Linux with GFORTRAN compiler V4.4+
- Mac with INTEL compiler V11.1
- Mac with PGI compiler V10.3-0 64-bit
- Mac with GFORTRAN compiler V4.4.0
- Mac with G95 compiler V0.9

✓ To check version numbers, use xlf -qversion, g95 -v, pgf90 -V, gfortran –v

Unsupported platforms

Due to lack of access to these platforms and compilers, we are unable to provide support:

- Sun (solaris)
- DEC alpha
- Other SGI
- Absoft
- Lahey
- Salford
- Pathscale

WRFDA does not work on

- PGI 5.x, GFORTRAN 4.3 and lower
- Windows

Please share with us (and other fellow users) your experiences on the various platforms and compilers.

Libraries Required by WRFDA

- **NetCDF**: Network Common Data Form:

  http://www.unidata.ucar.edu/software/netcdf/

Set environmental variable for the NetCDF library:

```
> setenv NETCDF $your_installation_dir/netcdf
```

✓ Make sure the NetCDF library is compiled using the same compiler that will be used to build WRFDA, since libraries produced by one compiler may not be compatible with code compiled by another.

Optional Libraries

- If using PREPBUFR or radiance data:
  - BUFR: Binary Universal Form for the Representation of meteorological data

    http://www.nco.ncep.noaa.gov/sib/decoders/BUFRLIB/

    Included in WRFDA (as of V3.1.1)
- If assimilating radiance data, either CRTM or RTTOV is required:
  - CRTM: Community Radiative Transfer Model (version REL_2.1.3)

    ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM/

    Included in WRFDA (as of V3.2.1)

  Set environmental variables:

  ```
  > setenv BUFR  1
  > setenv CRTM  1
  ```

  - RTTOV: Radiative Transfer for TOVS (version 11)

    http://research.metoffice.gov.uk/research/interproj/nwpsaf/rtm

  ```
  > setenv RTTOV path_where lib/librttov11.1.0_*.a
                      libraries are located
  ```

Configure WRFDA

> cd $your_sourcecode_dir/WRFDA

> **./configure wrfda**

- configure.wrf will be created

```
checking for perl5... no
checking for perl... found /usr/bin/perl (perl)
Will use NETCDF in dir: /usr/local/netcdf-3.6.0-p1-g95ppc
PHDF5 not set in environment. Will configure WRF for use without.
$JASPERLIB or $JASPERINC not found in environment, configuring to build without grib2 I/O...
------------------------------------------------------------------------
Please select from among the following supported platforms.

   1.  Darwin (MACOS) PGI compiler with pgcc  (serial)
   2.  Darwin (MACOS) PGI compiler with pgcc  (smpar)
   3.  Darwin (MACOS) PGI compiler with pgcc  (dmpar)
   4.  Darwin (MACOS) PGI compiler with pgcc  (dm+sm)
   5.  Darwin (MACOS) intel compiler with icc  (serial)
   6.  Darwin (MACOS) intel compiler with icc  (smpar)
   7.  Darwin (MACOS) intel compiler with icc  (dmpar)
   8.  Darwin (MACOS) intel compiler with icc  (dm+sm)
   9.  Darwin (MACOS) intel compiler with cc  (serial)
  10.  Darwin (MACOS) intel compiler with cc  (smpar)
  11.  Darwin (MACOS) intel compiler with cc  (dmpar)
  12.  Darwin (MACOS) intel compiler with cc  (dm+sm)
  13.  Darwin (MACOS) g95 with gcc  (serial)
  14.  Darwin (MACOS) g95 with gcc  (dmpar)
  15.  Darwin (MACOS) xlf   (serial)
  16.  Darwin (MACOS) xlf   (dmpar)

Enter selection [1-16] :
```

serial: single-processor

dmpar: distributed-memory parallel

smpar: shared-memory parallel

dm+sm: distributed-memory with shared-memory parallel

✓ On linux, smpar, dm+sm may not work properly because the MPI library may not be thread-safe.

Compile WRFDA

> ./compile all_wrfvar >&! log_compile

- □ 43 executables in the var/build directory (linked to var/da):
  - da_wrfvar.exe: WRFDA
  - da_update_bc.exe: update_bc
  - gen_be_stage0_wrf.exe, …: gen_be
  - da_advance_time.exe: time manipulation
- □ OBSPROC executable in the var/obsproc/src
  - obsproc.exe: OBSPROC

- Clean the WRFDA directory before making your next compilation:

  > clean -a

✓ **Note: WRF compiles with the -r4 option while WRFDA compiles with -r8.** For this reason, WRF and WRFDA cannot reside and be compiled under the same directory.

Setting-up a WRFDA-3DVar run

WRFDA-3DVar Equation

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_\mathrm{b})^\mathrm{T}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_\mathrm{b}) + \frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^\mathrm{T}\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x}))$$

J**(x):** Scalar cost function

x: The analysis: what we’re trying to find!

x$_\mathbf{b}$: Background field

B: Background error covariance matrix

y: Observations

H**:** Observation operator: computes model-simulated obs

R: Observation error covariance matrix

User-provided Data

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_\mathrm{b})^\mathrm{T}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_\mathrm{b}) + \frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^\mathrm{T}\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x}))$$

***J*(x):** Scalar cost function……………………….WRFDA output

x: The analysis…………………………………..WRFDA output

$\mathbf{x}_\mathbf{b}$: Background field……………………………..user input

B: Background error covariance matrix……user input

y: Observations…………………………………..user input

***H*:** Observation operator……………………..included in WRFDA

R: Observation error covariance matrix……user input

Sources of User-provided Data

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x_b})^{\mathrm{T}} \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x_b}) + \frac{1}{2}(\mathbf{y} - H(\mathbf{x}))^{\mathrm{T}} \mathbf{R}^{-1} (\mathbf{y} - H(\mathbf{x}))$$

- Where do the input files come from?

Symbol	**Description**	**Source**
$\mathbf{x_b}$	Background (“first-guess”)	real.exe or previous WRF forecast
B	Background error covariances	“gen_be” or default file provided with WRFDA
y	Observations	“obsproc” output or NCEP BUFR files
R	Observation error covariances	“obsproc” output or NCEP BUFR files

User-determined run-time options…the Namelist

✓The namelist variables discussed in the following slides refer to WRFDA-3DVar runs and conventional data assimilation only.

✓Please refer to specific lectures (background error covariance, radiance assimilation, …) for other namelist options.

What is a Namelist?

- The Fortran namelist (namelist.input) file allows the user to configure a WRFDA run *without* recompiling the code.
  - Specific Fortran 90 namelist format:

```
&namelistname          - start
…
/                      - end
```

- Descriptions of WRFDA namelist variables are given in the WRF User’s Guide and README.namelist in the WRFDA release (**WRFDA/var/README.namelist**).

WRFDA Namelist

- Default values of the namelist variables are defined by the WRFDA Registry (WRFDA/Registry/Registry.wrfvar).
- Fill namelist.input with non-default and desired variable values before running WRFDA.
- A WRFDA namelist file includes two parts:

```
&wrfvar1
/
&wrfvar2
/
…
&wrfvar22
/
&time_control
/
&fdda
/
…
&namelist_quilt
/
```

1) WRFDA namelist options:
Running options for WRFDA code.

2) WRF namelist options:
WRFDA needs certain information from the WRF configuration including domain and time settings.

✓Append your WRF namelist.input to the end of &wrfvar22 to create a complete/consistent namelist.input for WRFDA

Run-time Configurations

- The next several slides pose configuration questions that should be considered before making a WRFDA-3DVar run.
  - Important to carefully think about your configurations!

- The appropriate namelist parameters associated with these questions are discussed.

Background Options

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \boxed{\mathbf{x}_\mathrm{b}})^\mathrm{T}\mathbf{B}^{-1}(\mathbf{x} - \boxed{\mathbf{x}_\mathrm{b}}) + \frac{1}{2}(\mathbf{y} - H(\mathbf{x}))^\mathrm{T}\mathbf{R}^{-1}(\mathbf{y} - H(\mathbf{x}))$$

•***What's the format of my background file?***

&WRFVAR3

- fg_format: Format of the first guess field

  fg_format = 1 : ARW regional, default

  fg_format = 2 : WRF-NMM regional (not tested)

  fg_format = 3 : ARW global (not tested)

  fg_format = 4 : KMA global (not tested)

Background Error Covariance Options

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_\mathrm{b})^\mathrm{T}\boxed{\mathbf{B}^{-1}}(\mathbf{x}-\mathbf{x}_\mathrm{b}) + \frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^\mathrm{T}\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x}))$$

•***What type of background error covariance do I want to use?***

&WRFVAR7

- cv_options: Background error covariance option

  cv_options = 3 : global, default…see …/var/run/be.dat.cv3

  cv_options = 5 : regional, generated by “gen_be”

  cv_options = 6 : regional, generated by “gen_be” with multivariate moisture correlation, new in WRFDA V3.3

Observation Options

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_\mathrm{b})^\mathrm{T}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_\mathrm{b}) + \frac{1}{2}(\boxed{\mathbf{y}} - H(\mathbf{x}))^\mathrm{T}\mathbf{R}^{-1}(\boxed{\mathbf{y}} - H(\mathbf{x}))$$

•***What's the format of my conventional observations?***

&WRFVAR3

- ob_format: The format of the conventional and satellite retrieval observation data going into WRFDA

  ob_format = 1 : NCEP PREPBUFR (ob.bufr)
  ob_format = 2 : ASCII (ob.ascii), default

  ob_format_gpsro = 1 : Read GPSRO data from NCEP BUFR
  ob_format_gpsro = 2 : Read GPSRO data from ASCII, default

Observation Options

- ***What observation types do I want to assimilate?***

```
&WRFVAR4
 USE_SYNOPOBS =  T,
 USE_SHIPSOBS =  T,
 USE_METAROBS =  T,
 USE_SOUNDOBS =  T,
 USE_PILOTOBS =  T,
 USE_AIREPOBS =  T,
 USE_GEOAMVOBS =  T,
 USE_POLARAMVOBS =  T,
 USE_BUOYOBS =  T,
 USE_PROFILEROBS =  T,
 USE_SATEMOBS =  T,
 USE_GPSZTDOBS =  F,
 USE_GPSPWOBS =  T,
 USE_GPSREFOBS =  T,
 USE_QSCATOBS =  T,
 USE_RADAROBS =  F,
 USE_RADAR_RV =  F,
 USE_RADAR_RF =  F,
 USE_AIRSRETOBS =  T,
```

Assimilate this observation type?

Set to either True or False

Observation Options

- ***How much do I want to thin my PREPBUFR obs?***

&WRFVAR4—only for NCEP PREPBUFR OBS (ob_format = 1)

- thin_conv: For thinning NCEP PREFPBUFR obs

  thin_conv = .true. : default, *should always set to true*

  thin_conv = .false. : Used only for debugging purposes.

- thin_mesh_conv (max_instruments): Thinning mesh (km) for each type of conventional observation. The observation index/order follows the definitions in WRFDA/var/da/da_control/da_control.f90 (e.g., sound =1, synop =2, …)

  By default, thin_mesh_conv = 20.0 (km)

Observation Options

- ***What time window for my observations do I want to use?***

&WRFVAR21

- time_window_min = “2008-02-05_10:30:00”

&WRFVAR22

- time_window_max = “2008-02-05_13:30:00”

- Obs between time_window_min and time_window_max are processed.

- Note the “WRF format” of the times

Observation Options

•***How strictly do I want to reject conventional observations?***

&WRFVAR5

- check_max_iv: Turns on/off an “outlier check” to reject observations whose innovations (O-B) are larger than a value defined as a multiple (a) of the observation error (σ_o) for each observation: i.e., when O-B > (a*σ_o), the ob is rejected.

  check_max_iv = .true. : default, typically set to true

  check_max_iv = .false. : Use this option only if the observation data are known to have good quality.

- max_error_t, max_error_uv, max_error_pw, max_error_q, max_error_ref, max_error_rv, max_error_p: The factors (a) that multiply σ_o in the check_max_iv test. Can be set individually for different meteorological variables.

  By default, max_error* = 5.0 for all meteorological variables

Observation Options

•*How do I want to handle surface observations?*

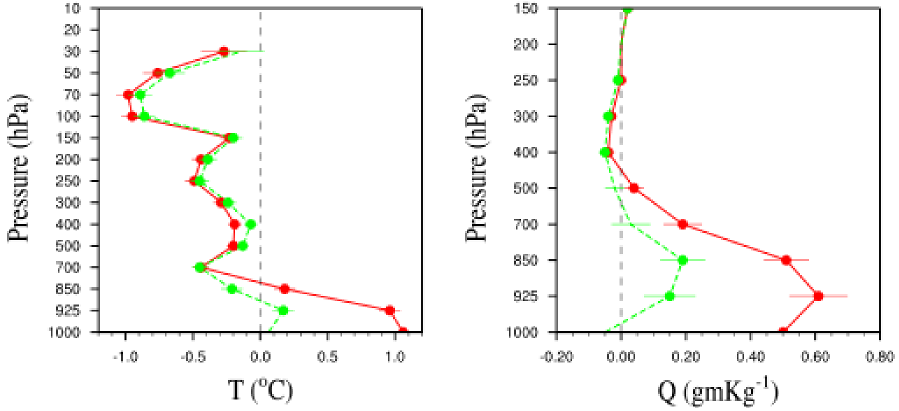
&WRFVAR11

- sfc_assi_options:

  sfc_assi_options = 1 (default): The surface observations will be assimilated based on the lowest model level first guess. Observations are not used when the height difference of the elevation of observing site and the lowest model level height is larger than 100 meters.

  sfc_assi_options = 2: The surface observations will be assimilated based on surface similarity theory in PBL. Innovations are computed based on 10-m wind and 2-m temperature & moisture.

✓ Please use this option with caution, since the results could be very sensitive.



Analysis Options

$$\boxed{J(\mathbf{x})}=\frac{1}{2}(\boxed{\mathbf{x}}-\mathbf{x}_{\mathrm{b}})^{\mathrm{T}}\mathbf{B}^{-1}(\boxed{\mathbf{x}}-\mathbf{x}_{\mathrm{b}})+\frac{1}{2}(\mathbf{y}-H(\boxed{\mathbf{x}}))^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{y}-H(\boxed{\mathbf{x}}))$$

•***At what time is my analysis valid?***

&WRFVAR18

- analysis_date = “2008-02-05_12:00:00”

(should be the same time as in your first-guess file)

Analysis Options

- ***How do I want to configure minimization options?***

&WRFVAR6

- max_ext_its: Number of outer loops.
  - 1: default. Only one outer loop.
  - Maximum number of outer loops is 10; common application is 2.

- eps: Value for minimization convergence criterion. It is an array of dimension=max_ext_its.
  - 0.01(max_ext_its): default. The minimization is considered to converge when the norm of the cost function gradient is reduced at least 2 orders.

- ntmax: Maximum number of iterations in an inner loop for the minimization in WRFDA.
  - 200(max_ext_its): default. The minimization in the inner loop stops when either the ntmaxth iteration is reached or the eps criterion is met.

Analysis Options

•***What type of analysis do I want to perform?***

&WRFVAR17

- analysis_type: Indicates job type of WRFDA.

analysis_type = "3D-VAR" (default): Run 3DVar data assimilation.

analysis_type = "RANDOMCV": Creates ensemble perturbations.

analysis_type = "VERIFY" : Run WRFDA in verification mode (forces check_max_iv=.false. and ntmax=0).

✓ Please refer to "**WRFDA Tools and Verification package**" talk.

analysis_type = "QC-OBS": Run 3DVar data assimilation and produce filtered_obs file.

✓ By combining with check_max_iv=.true. and ntmax=0, you can produce a WRFDA filtered (QCd) observation data set (filtered_obs) without running data assimilation.

Analysis Options

•***How much output information do I want?***

&WRFVAR1

- print_detail_grad

  print_detail_grad = .false. (default)

  print_detail_grad = .true.

  Output cost function and gradient values of every observation type each iteration into standard output files (rsl.out)

Analysis Options

•*How much output information do I want?*

&WRFVAR11

- calculate_cg_cost_fn:

  calculate_cg_cost_fn = .false. (default) : Only the initial and final cost functions are computed and output in files called "cost_fn" and "grad_fn".

  calculate_cg_cost_fn = .true. : The cost functions are derived and output at every iteration for diagnostic purposes in "cost_fn" and "grad_fn".

calculate_cg_cost_fn = .false.

```
Outer    EPS     Inner     J          Jb       Jo          Jc         Je         Jp
Iter              Iter
   1  0.100E-01     0  11251.182     0.000  11251.182     0.000      0.000      0.000
   1  0.100E-01    19   8634.570   885.427   7749.143     0.000      0.000      0.000
```

calculate_cg_cost_fn = .true.

```
Outer    EPS     Inner     J          Jb       Jo          Jc         Je         Jp
Iter              Iter
   1  0.100E-01     0  11251.182     0.000  11251.182     0.000      0.000      0.000
   1  0.100E-01     1  10384.156    41.768  10342.388     0.000      0.000      0.000
   1  0.100E-01     2   9633.557   184.109   9449.448     0.000      0.000      0.000
   1  0.100E-01     3   9245.700   327.121   8918.579     0.000      0.000      0.000
   1  0.100E-01     4   9014.861   453.787   8561.075     0.000      0.000      0.000
   1  0.100E-01     5   8872.989   559.714   8313.275     0.000      0.000      0.000
   1  0.100E-01     6   8777.974   652.105   8125.869     0.000      0.000      0.000
   1  0.100E-01     7   8720.998   721.735   7999.263     0.000      0.000      0.000
   1  0.100E-01     8   8689.342   768.464   7920.878     0.000      0.000      0.000
   1  0.100E-01     9   8665.605   810.136   7855.469     0.000      0.000      0.000
   1  0.100E-01    10   8654.051   833.590   7820.461     0.000      0.000      0.000
   1  0.100E-01    11   8646.376   851.091   7795.285     0.000      0.000      0.000
   1  0.100E-01    12   8641.869   862.515   7779.355     0.000      0.000      0.000
   1  0.100E-01    13   8638.219   872.853   7765.365     0.000      0.000      0.000
   1  0.100E-01    14   8636.669   877.707   7758.962     0.000      0.000      0.000
   1  0.100E-01    15   8635.794   880.667   7755.127     0.000      0.000      0.000
   1  0.100E-01    16   8635.176   882.929   7752.247     0.000      0.000      0.000
   1  0.100E-01    17   8634.861   884.169   7750.693     0.000      0.000      0.000
   1  0.100E-01    18   8634.686   884.909   7749.777     0.000      0.000      0.000
   1  0.100E-01    19   8634.570   885.427   7749.143     0.000      0.000      0.000
```

List of some namelist variables that are most likely to be user-modified (for conventional observations…red, discussed herein)

```
&WRFVAR1
 PRINT_DETAIL_GRAD = F,

&WRFVAR3
 FG_FORMAT = 1,
 OB_FORMAT = 2,
 NUM_FGAT_TIME = 1

&WRFVAR4
 THIN_CONV =  T,
 THIN_MESH_CONV = 30*20.0
 USE_SYNOPOBS =  T,
 USE_SHIPSOBS =  T,
 USE_METAROBS =  T,
 USE_SOUNDOBS =  T,
 USE_PILOTOBS =  T,
 USE_AIREPOBS =  T,
 USE_GEOAMVOBS =  T,
 USE_POLARAMVOBS =  T,
 USE_BUOYOBS =  T,
 USE_PROFILEROBS =  T,
 USE_SATEMOBS =  T,
 USE_GPSZTDOBS =  F,
 USE_GPSPWOBS =  T,
 USE_GPSREFOBS =  T,
 USE_QSCATOBS =  T,
 USE_RADAROBS =  F,
 USE_RADAR_RV =  F,
 USE_RADAR_RF =  F,
 USE_AIRSRETOBS =  T,
```

```
&WRFVAR5
 CHECK_MAX_IV =  T,
 MAX_ERROR_T    = 5.0,
 MAX_ERROR_UV   = 5.0,
 MAX_ERROR_PW   = 5.0,
 MAX_ERROR_REF = 5.0,
 MAX_ERROR_Q    = 5.0,
 MAX_ERROR_P    = 5.0,
 MAX_ERROR_RV   = 5.0,
 MAX_ERROR_RF   = 5.0,

&WRFVAR6
 MAX_EXT_ITS = 1,
 NTMAX = 200,
 EPS = 0.01, 0.01, 0.01

&WRFVAR7
 CV_OPTIONS = 5,
 AS1 = 0.25, 1.0, 1.5,
 AS2 = 0.25, 1.0, 1.5,
 AS3 = 0.25, 1.0, 1.5,
 AS4 = 0.25, 1.0, 1.5,
 AS5 = 0.25, 1.0, 1.5,
 RF_PASSES = 6,
 VAR_SCALING1 = 1.0,
 VAR_SCALING2 = 1.0,
 VAR_SCALING3 = 1.0,
 VAR_SCALING4 = 1.0,
 VAR_SCALING5 = 1.0,
 LEN_SCALING1 = 1.0,
 LEN_SCALING2 = 1.0,
 LEN_SCALING3 = 1.0,
 LEN_SCALING4 = 1.0,
 LEN_SCALING5 = 1.0,
```

```
&WRFVAR11
 CHECK_RH = 0,
 SFC_ASSI_OPTIONS = 1,
 CALCULATE_CG_COST_FN = F,

&WRFVAR15
 NUM_PSEUDO = 0,
 PSEUDO_X = 1.0,
 PSEUDO_Y = 1.0,
 PSEUDO_Z = 1.0,
 PSEUDO_VAL = 1.0,
 PSEUDO_ERR = 1.0

&WRFVAR17
 ANALYSIS_TYPE = “3D-VAR”

&WRFVAR18
 ANALYSIS_DATE = “2008-02-05_12:00:00”

&WRFVAR19
 PSEUDO_VAR = “t”

&WRFVAR21
 TIME_WINDOW_MIN = “2008-02-05_10:30:00”

&WRFVAR22
 TIME_WINDOW_MAX = “2008-02-05_13:30:00”
```

✓ Append your WRF namelist.input to the end of &wrfvar22 to create a complete/consistent namelist.input for WRFDA

Running WRFDA-3DVar

Before You Run…

- Ensure the WRFDA executable has been created successfully
  - WRFDA/var/build/da_wrfvar.exe

- Get input files:
  - The test data (WRFV3-Var-testdata.tar) can be downloaded from http://www.mmm.ucar.edu/wrf/users/wrfda/download/test_data.html
  - Extract the test data into your local data directory, e.g., "*your_choice_of_dat_dir*".
  - Set up your environmental variable $DAT_DIR:

    > setenv DAT_DIR *your_choice_of_dat_dir*

Before You Run…

$$J(\mathbf{x})=\frac{1}{2}(\mathbf{x}-\mathbf{x_b})^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x_b})+\frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x}))$$

- Check input files:
  - Background ($\mathbf{x_b}$): $DAT_DIR/rc/2007010200/wrfinput_d01
    - NETCDF format.
    - For cold-start mode, $\mathbf{x_b}$ is generated by WRF "real.exe"
    - For cycling mode, $\mathbf{x_b}$ is generated by WRF from a previous cycle's forecast.
  - Background Error Statistics (**B**): $DAT_DIR/be/be.dat
    - Binary format.
    - Generated by "gen_be" for this specific test case domain.
    - Please refer to "**WRFDA Background Error Estimations**" talk.
  - Observations (**y,R**) : $DAT_DIR/ob/2007010200/ob.little_r (conventional obs only)
    - ASCII or PREPBUFR format.
    - Generated by OBSPROC from obs.2007010200, included in the tar file of the test data.
    - Please refer to "**Radiance Data Assimilation**" talk for assimilating radiance data.
- Prepare a WRFDA namelist containing runtime options:
  - WRFDA/var/test/tutorial/namelist.input (example)

WRFDA-3DVar Input

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}_\mathbf{b})^\mathrm{T}\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_\mathbf{b}) + \frac{1}{2}(\mathbf{y} - H(\mathbf{x}))^\mathrm{T}\mathbf{R}^{-1}(\mathbf{y} - H(\mathbf{x}))$$

Symbol	Description	**WRFDA names**
$\mathbf{x}_\mathbf{b}$	Background ("first-guess")	./fg
$\mathbf{y}$	Observations	./ob.ascii OR ./ob.bufr
$\mathbf{R}$	Observation error covariances	./ob.ascii OR ./ob.bufr
$\mathbf{B}$	Background error covariances	./be.dat
N/A	User-defined run-time options (namelist)	./namelist.input
N/A	Land-use table	./LANDUSE.TBL
N/A	WRFDA executable	./da_wrfvar.exe

Working Directory - Input

- Create a working directory, for example, “*your_choice_of_ working_dir*”.

```
> mkdir -p your_choice_of_working_dir
```

- Go into the working directory:

```
> cd your_choice_of_working_dir
```

- Prepare the input files (link or copy) for running WRFDA:

```
>  ln -sf WRFDA/var/build/da_wrfvar.exe    ./da_wrfvar.exe
> ln -sf WRFDA/run/LANDUSE.TBL            ./LANDUSE.TBL
> ln -sf $DAT_DIR/rc/2007010200/wrfinput_d01  ./fg
> ln -sf $DAT_DIR/be/be.dat                   ./be.dat
> ln -sf $DAT_DIR/ob/2007010200/ob.little_r   ./ob.ascii
> cp WRFDA/var/test/namelist.input        ./namelist.input
```

(or use your own namelist)

Running WRFDA

```
> ./da_wrfvar.exe >&! wrfda.log
```

```
> mpirun –np 8 ./da_wrfvar.exe
```

If running in distributed-memory mode, you need to set up the computer resources (e.g., processor numbers, memory, wallclock…) based on the platform you are using. The log file names will be rsl.out.0000, rsl.out.0001,…

Working Directory - Output

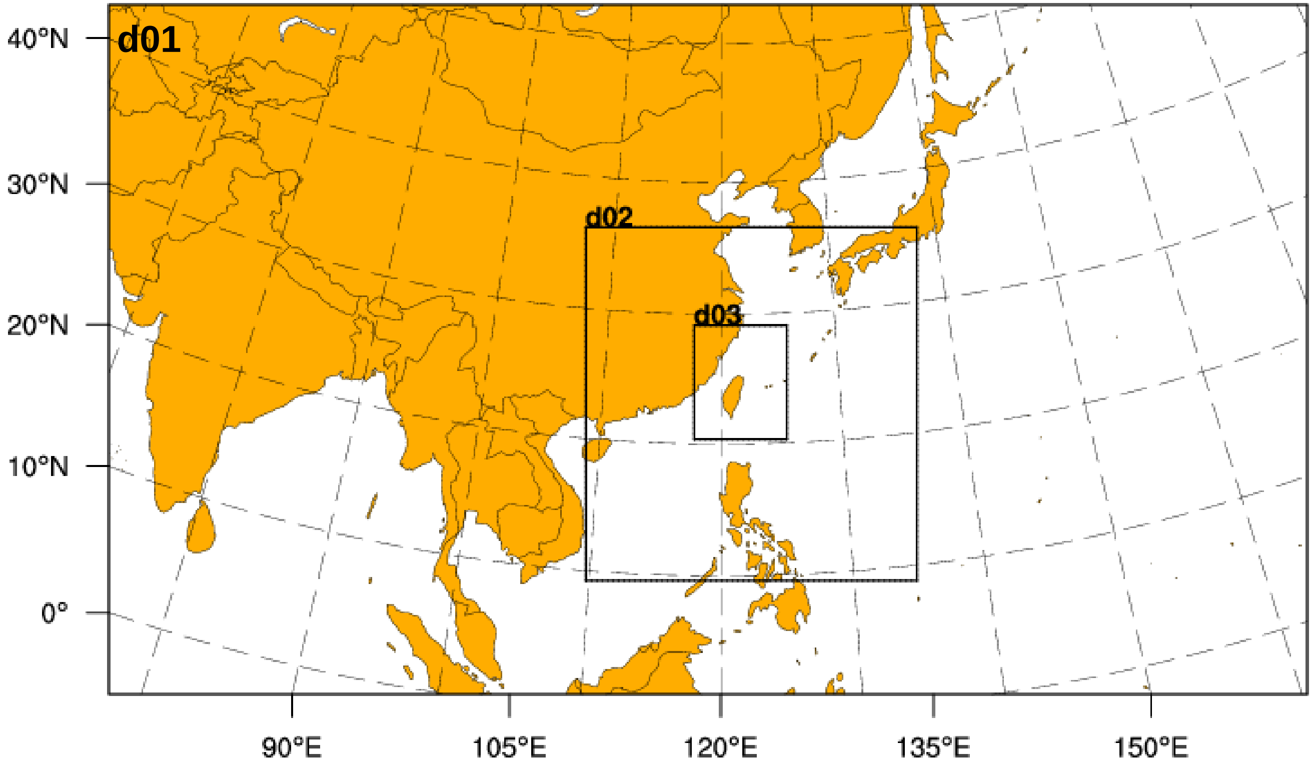
In *your_choice_of_working_dir*, you should have at least the following files after WRFDA is successfully completed:

- cost_fn (Cost function)
- grad_fn (Gradient of cost function)
- gts_omb_oma_01 (point-by-point O, O-B, O-A information, etc.)
- namelist.output (Complete namelist)
- statistics (domain-wide O-B and O-A statistics)
- **wrfvar_output (Analysis x,** the input to the WRF model)

O: Observation
A: Analysis
B: Background (first-guess)

A word about nested domains

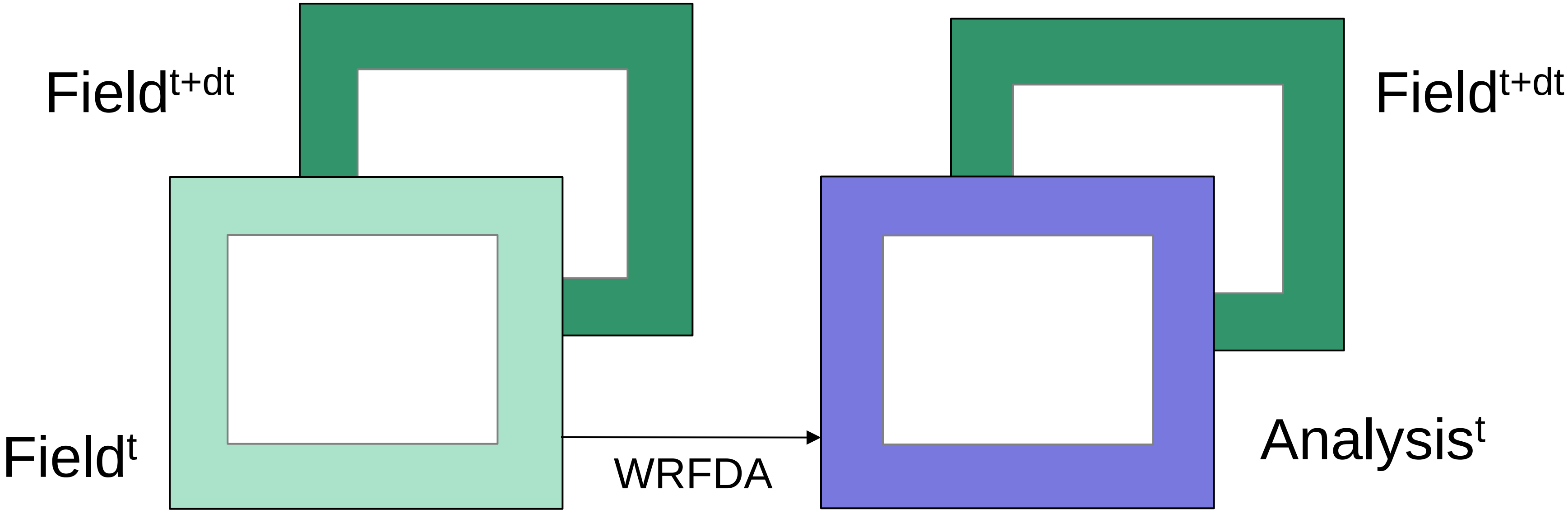
- WRFDA can only process one file/domain at a time
  - If you wish to run WRFDA for multiple nests, need to run WRFDA separately for each nest



Running update_bc

update_bc

- ***Why do we need update_bc?***
- Need to update lateral boundary points to reflect our analysis
- Need to update lateral boundary *tendencies* for the first time
- Can also update lower boundary conditions



wrfbdy contains the *tendency* (Field^{t+dt}– Field^{t})/dt

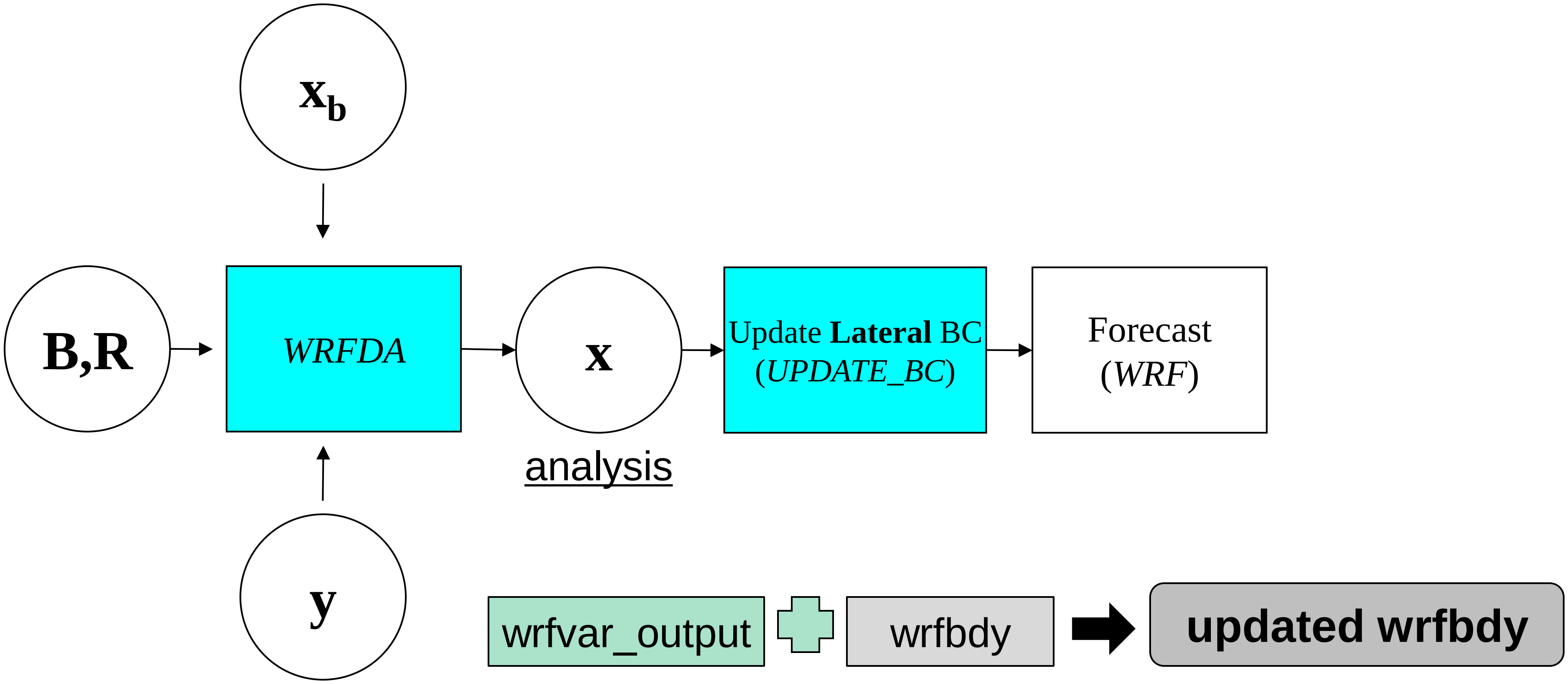
wrfbdy needs to be updated to be (Field^{t+dt}– Analysis^{t})/dt after WRFDA

Applications of update_bc

- Cold-start initial conditions (i.e., first-guess from “real.exe”):
  - Update **lateral** boundaries **after** running WRFDA
  - No need to update low boundary before running WRFDA
- Cyclic initial conditions (i.e., first-guess from previous forecast):
  - Update **low** BC **before** running WRFDA
  - Update **lateral** BCs **after** running WRFDA
- Dealing with nested domains:
  - For coarse domain (domain_id = 1), update **low** boundary **before** running WRFDA (if cycling) and **lateral** boundaries **after** running WRFDA
  - For fine mesh domains (domain_id > 1) update **low** boundary for each nest **before** running WRFDA (if cycling)…DO NOT update lateral boundaries

update_bc (lateral boundary condition)

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}_\mathrm{b})^\mathrm{T}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_\mathrm{b}) + \frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^\mathrm{T}\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x}))$$



$\mathbf{x}_\mathrm{b}$

$\mathbf{B},\mathbf{R}$

WRFDA

$\mathbf{y}$

$\mathbf{x}$

analysis

Update **Lateral** BC (*UPDATE_BC*)

Forecast (*WRF*)

wrfvar_output + wrfbdy → **updated wrfbdy**

- Always update **lateral** BC **after** running WRFDA for outermost domain

Steps to Run update_bc (for lateral BC)

- Make sure UPDATE_BC executable has been created successfully:
  - WRFDA/var/build/da_update_bc.exe

- Go into the working directory and prepare the input files for update_bc:

```
> cd your_choice_of_working_dir
> cp ${DAT_DIR}/rc/2007010200/wrfbdy_d01   ./wrfbdy_d01
> ln –sf WRFDA/var/build/da_update_bc.exe  ./da_update_bc.exe
```

- Prepare the namelist for update_bc: *parame.in*

```
&control_param
 da_file      = ‘./wrfvar_output’   - Analysis from WRFDA
 wrf_bdy_file = ‘./wrfbdy_d01’      - BC from WPS and WRF real
 debug        = .true.
  update_lateral_bdy = .true.
 update_low_bdy     = .false.
 iswater            = 16       - Should be 17 if using MODIS land-use
/
```

- ./da_update_bc.exe > &! da_update_bc_latbdy.log

(updating **low** boundary for **cycling** runs)

da_update_bc: **update_low_bdy**

TSK: surface skin temperature (over water)
TMN: soil temperature at lower boundary
SST: sea surface temperature
VEGFRA: vegetation fraction
ALBBCK: background snow-free albedo
SEAICE: sea ice flag

IVGTYP: dominant vegetation category (integer)
ISLTYP: dominant soil category (integer)
LANDMASK: 1=land, 0=water
XLAND: 1=land, 2=water

fields need to be consistent with **SEAICE**

SNOW: snow water equivalent
SNOWC: snow cover
SNOWH: snow depth

snow over water needs to be removed

da_update_bc: update_low_bdy & **update_lsm**

SNOW: snow water equivalent
CANWAT: canopy water
RHOSN: snow density
SNOWH: snow depth
SNOWC: snow cover
TSLB: soil temperature
SMOIS: soil moisture
SH2O: soil liquid water

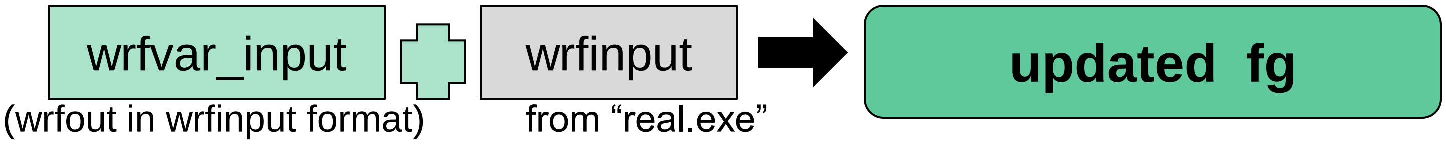
WRFDA adds increments to

- U
- V
- T
- PSFC
- QVAPOR

and modifies

- PH
- P
- MU
- U10
- V10
- T2
- Q2

update_bc (low boundary condition)



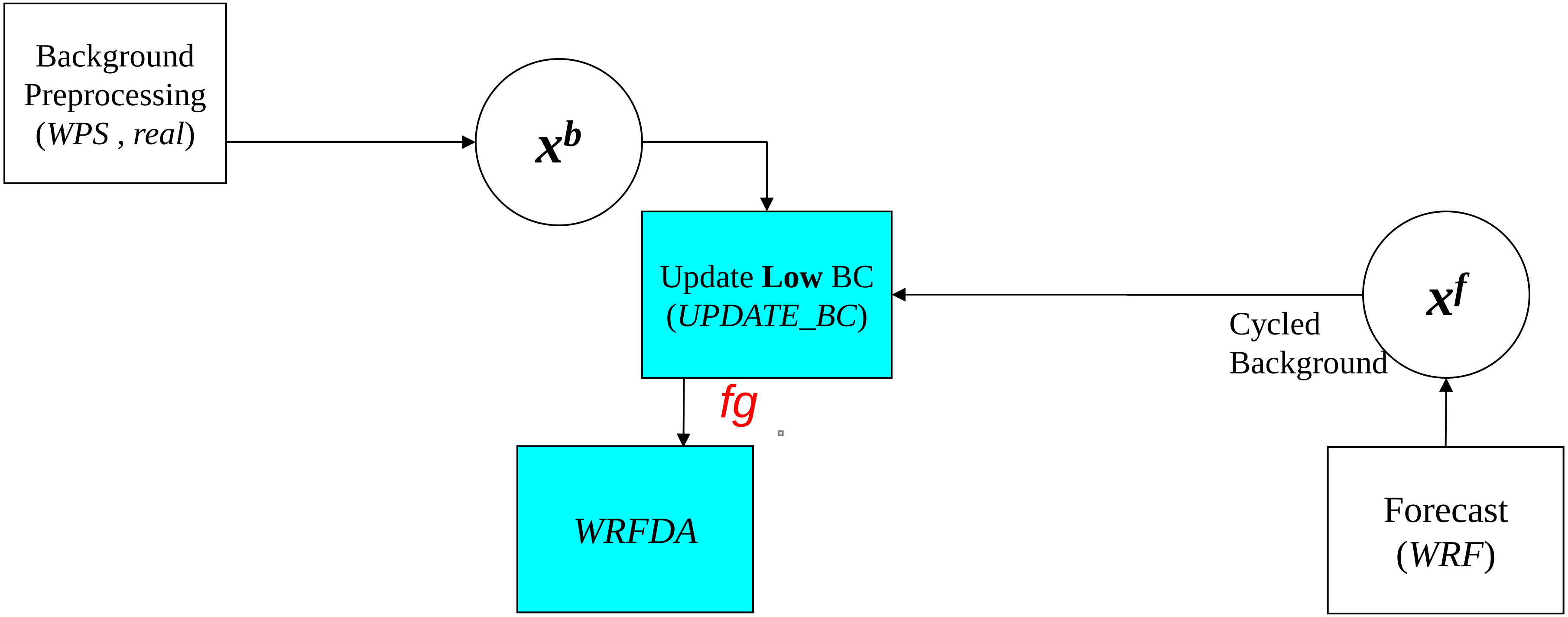
wrfvar_input

(wrfout in wrfinput format)

wrfinput

from “real.exe”

updated fg



Background Preprocessing (*WPS* , *real*)

x^b

Update **Low** BC (*UPDATE_BC*)

x^f

Cycled Background

fg

WRFDA

Forecast (*WRF*)

- Only need to update low BC if using cyclic initial conditions

Steps to Run update_bc (for low BC)

- Make sure UPDATE_BC executable has been created successfully:
  - WRFDA/var/build/da_update_bc.exe

- Go into the working directory and prepare the input files for update_bc:

```
> cd your_choice_of_working_dir
> cp ${your_wrf_run_dir}/wrfvar_input_d01  ./fg
> ln –sf WRFDA/var/build/da_update_bc.exe  ./da_update_bc.exe
```

- Prepare the namelist for update_bc: *parame.in*

```
&control_param
 da_file       = ‘./fg’         - First guess (wrfout in wrfinput format) for WRFDA
 wrf_input     = ‘${DAT_DIR}/rc/2007010200/wrfinput_d01’ - IC from WPS and WRF real
  debug        = .true.
  update_lateral_bdy = .false.
 update_low_bdy     = .true.
 iswater            = 16       - Should be 17 if using MODIS land-use
/
```

- ./da_update_bc.exe > &! da_update_bc_lowbdy.log

WRFDA-3DVar Diagnostics

ASCII output files in the WRFDA working directory:

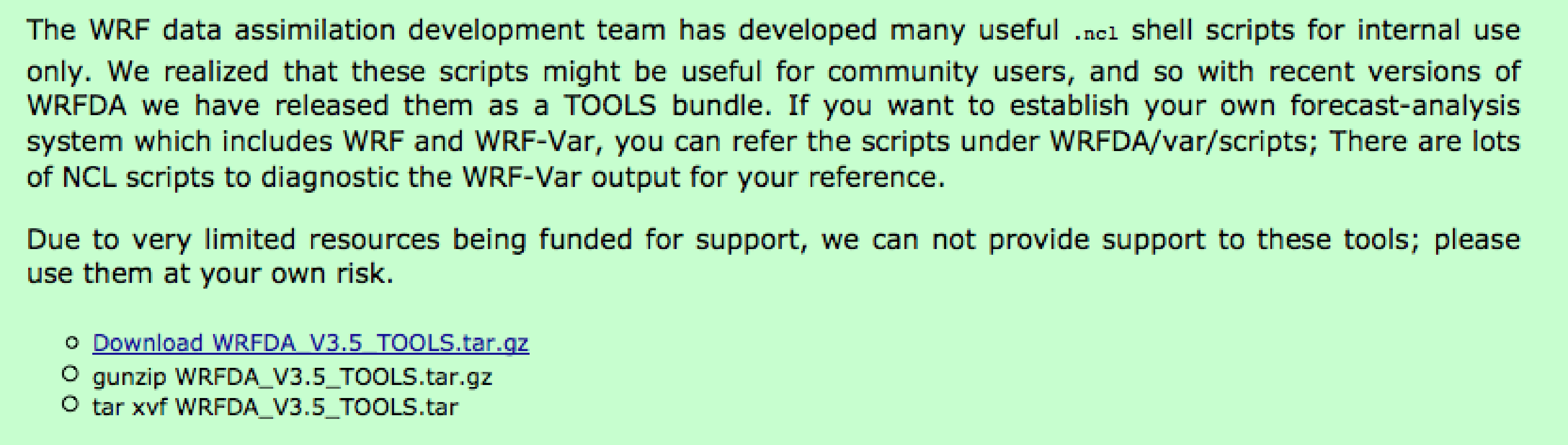
- wrfda.log or rsl.out.0000
- namelist.output
- filtered_obs_01 (analysis_type="QC-OBS")
- rej_obs_conv_01.000
- qcstat_conv_01
- cost_fn
- grad_fn
- gts_omb_oma_01
- statistics
- jo

After each WRFDA run, it is important to:

✓ Check the log file (or rsl.out.0000) to see if WRFDA has completed successfully, how many iterations it took to converge, etc.

✓ Check the statistics file to see if the values are reasonable

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



The WRF data assimilation development team has developed many useful `.ncl` shell scripts for internal use only. We realized that these scripts might be useful for community users, and so with recent versions of WRFDA we have released them as a TOOLS bundle. If you want to establish your own forecast-analysis system which includes WRF and WRF-Var, you can refer the scripts under WRFDA/var/scripts; There are lots of NCL scripts to diagnostic the WRF-Var output for your reference.

Due to very limited resources being funded for support, we can not provide support to these tools; please use them at your own risk.

- ○ Download WRFDA_V3.5_TOOLS.tar.gz
- ○ gunzip WRFDA_V3.5_TOOLS.tar.gz
- ○ tar xvf WRFDA_V3.5_TOOLS.tar

✓var/graphics/ncl contains various NCL plotting scripts, see var/graphics/ncl/README

wrfda.log (rsl.out.0000)

- Very important information about your WRFDA run, including observation summary, values of cost function and its gradient, etc.

- Additional diagnostics may be printed in these files by including various "print_detail_xxx" WRFDA namelist options (&wrfvar1)(using these options, the log file size could become quite large).

```
***  VARIATIONAL ANALYSIS ***
 DYNAMICS OPTION: Eulerian Mass Coordinate
 WRF NUMBER OF TILES =   1
Set up observations (ob)
```

```
Final:  15 iter, J= 1.76436785D+04, g= 2.06098421D+00
------------------------------------------------------------

Diagnostics
   Final cost function J        =     17643.68
   Total number of obs.         =    26726
   Final value of J             =     17643.67853
   Final value of Jo            =     15284.64894
   Final value of Jb            =      2359.02958
   Final value of Jc            =         0.00000
   Final value of Je            =         0.00000
   Final value of Jp            =         0.00000
   Final J / total num_obs      =         0.66017
   Jb factor used(1)            =         1.00000
   Jb factor used(2)            =         1.00000
   Jb factor used(3)            =         1.00000
   Jb factor used(4)            =         1.00000
   Jb factor used(5)            =         1.00000
   Jb factor used               =         1.00000
   Je factor used               =         1.00000
   VarBC factor used            =         1.00000

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

namelist.output

- When WRFDA is run, a namelist.output file is produced with all values of namelist variables (default and/or from namelist.input).

namelist.input

```
&wrfvar1
print_detail_grad=.true.
/
&wrfvar2
/
&wrfvar3
ob_format=2,
num_fgat_time=1,
/
&wrfvar4
use_synopobs=.false.
/
```

namelist.output

```
&WRFVAR1
 WRITE_INCREMENTS = F, WRFVAR_MEM_MODEL = 0, VAR4D = F,
MULTI_INC = 0, VAR4D_COUPLING = 2, PRINT_DETAIL_RADAR = F,
PRINT_DETAIL_RAD = F, PRINT_DETAIL_XA = F, PRINT_DETAIL_XB = F,
PRINT_DETAIL_OBS = F, PRINT_DETAIL_F_OBS = F, PRINT_DETAIL_MAP = F,
PRINT_DETAIL_GRAD = T, PRINT_DETAIL_REGRESSION = F,
PRINT_DETAIL_SPECTRAL = F,
PRINT_DETAIL_TESTING = F, PRINT_DETAIL_PARALLEL = F, PRINT_DETAIL_BE
= F,
CHECK_MAX_IV_PRINT = T, CHECK_BUDDY_PRINT = F,
 /
&WRFVAR2
ANALYSIS_ACCU = 900, CALC_W_INCREMENT = F, DT_CLOUD_MODEL = F,
WRITE_MOD_FILTERED_OBS = F,
 /
&WRFVAR3
FG_FORMAT=1, OB_FORMAT=2, NUM_FGAT_TIME=1
 /
&WRFVAR4
USE_SYNOPOBS=F, USE_SHIPSOBS=T, USE_METAROBS=T, USE_SOUNDOBS=T,
USE_MTGIRSOBS=T, USE_PILOTOBS=T,
```

filtered_obs_01

- Similar to ob.ascii (observation input file to WRFDA) but contains the observations filtered by WRFDA

- To output this file, set WRFDA namelist option: analysis_type = "QC-OBS" (&wrfvar17)

- What is filtered_obs for?
  - Can be used for checking what observations are actually assimilated in WRFDA
  - Can be used for running WRFDA in VERIFY mode with analysis_type = "VERIFY"

- filtered_obs should NOT be used for running regular WRFDA

rej_obs_conv_01.000

- Contains observations that fail check_max_iv check (if check_max_iv = .true.)
  - ✓ 01: outer loop index.
  - ✓ 000: processor id.

- See slide 25 and &wrfvar5

Obs_type	Variable	Lat	Lon	Pressure
sound	T	50.68	-127.36	215.00
sound	Q	50.68	-127.36	215.00
sound	U	47.46	-111.38	850.00
sound	V	31.86	-106.70	400.00
synop	U	50.11	-127.93	991.10
synop	V	48.76	-123.11	994.50
synop	Ps	53.43	-114.71	1013.01
synop	Q	53.43	-114.71	1013.01
gpsref	GpsR	36.26	-71.36	53.34
qscat	V	23.20	-74.22	1013.25

qcstat_conv_01

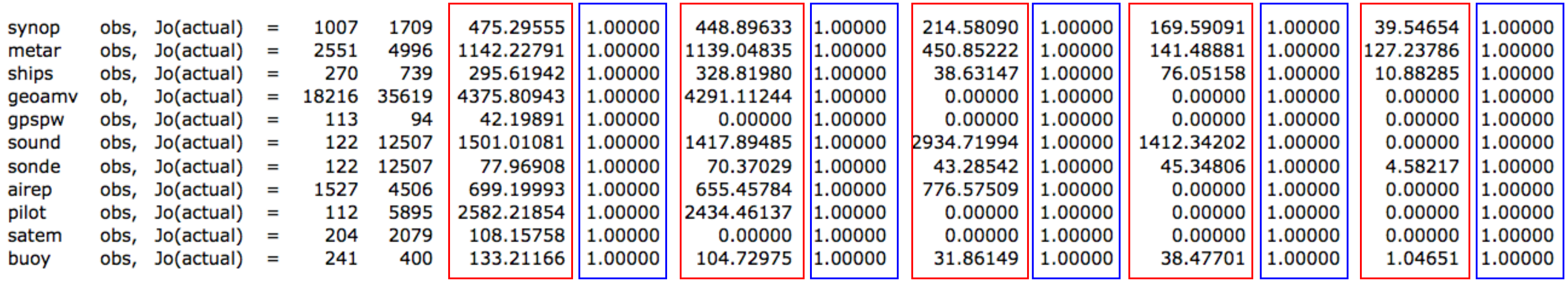
- Contains the number of observations that pass or fail WRFDA’s internal QC (e.g., check_max_iv check) for observations with pressure as a vertical coordinate
  - ✓ 01: outer loop index.

```
WRF-Var data utilization statistics for outer iteration   1

                    ptop  1000.0  900.0  800.0  600.0  400.0  300.0  250.0  200.0  150.0  100.0   50.0    0.0
 obs type var   pbot  1200.0  999.9  899.9  799.0  599.9  399.9  299.9  249.9  199.9  149.9   99.9 2000.0
------------------------------------------------------------------------------------------
 sound    U   used       20     29      37      48      91      41      41      44      45      79    99   574
                rej        1      2       0       0       0       0       0       0       0       0     0     3
 sound    V   used       21     30      37      48      91      41      41      44      45      79    99   576
                rej        0      1       0       0       0       0       0       0       0       0     0     1
 sound    T   used       32    135    130     452     447     200     118      68     113     191   293  2179
                rej        0      2       0       0       0       0       0       0       1       6     5    14
 sound    Q   used       32    135    130     451     439     193     105      53      81     159   218  1996
                rej        0      0       0       0       4       3       0       1       1       4     2    15
 synop    U   used       83      0       0       0       0       0       0       0       0       0     0    83
                rej        1      0       0       0       0       0       0       0       0       0     0     1
 synop    V   used       83      0       0       0       0       0       0       0       0       0     0    83
                rej        1      0       0       0       0       0       0       0       0       0     0     1
 synop    T   used      137      0       0       0       0       0       0       0       0       0     0   137
                rej        0      0       0       0       0       0       0       0       0       0     0     0
 synop    Q   used      130      0       0       0       0       0       0       0       0       0     0   130
                rej        4      0       0       0       0       0       0       0       0       0     0     4
```

jo

- Contains cost function of each observation type:



```
synop   obs,  Jo(actual)  =   1007   1709    475.29555  1.00000    448.89633  1.00000    214.58090  1.00000    169.59091  1.00000    39.54654  1.00000
metar   obs,  Jo(actual)  =   2551   4996   1142.22791  1.00000   1139.04835  1.00000    450.85222  1.00000    141.48881  1.00000   127.23786  1.00000
ships   obs,  Jo(actual)  =    270    739    295.61942  1.00000    328.81980  1.00000     38.63147  1.00000     76.05158  1.00000    10.88285  1.00000
geoamv  ob,   Jo(actual)  =  18216  35619   4375.80943  1.00000   4291.11244  1.00000      0.00000  1.00000      0.00000  1.00000     0.00000  1.00000
gpspw   obs,  Jo(actual)  =    113     94     42.19891  1.00000      0.00000  1.00000      0.00000  1.00000      0.00000  1.00000     0.00000  1.00000
sound   obs,  Jo(actual)  =    122  12507   1501.01081  1.00000   1417.89485  1.00000   2934.71994  1.00000   1412.34202  1.00000     0.00000  1.00000
sonde   obs,  Jo(actual)  =    122  12507     77.96908  1.00000     70.37029  1.00000     43.28542  1.00000     45.34806  1.00000     4.58217  1.00000
airep   obs,  Jo(actual)  =   1527   4506    699.19993  1.00000    655.45784  1.00000    776.57509  1.00000      0.00000  1.00000     0.00000  1.00000
pilot   obs,  Jo(actual)  =    112   5895   2582.21854  1.00000   2434.46137  1.00000      0.00000  1.00000      0.00000  1.00000     0.00000  1.00000
satem   obs,  Jo(actual)  =    204   2079    108.15758  1.00000      0.00000  1.00000      0.00000  1.00000      0.00000  1.00000     0.00000  1.00000
buoy    obs,  Jo(actual)  =    241    400    133.21166  1.00000    104.72975  1.00000     31.86149  1.00000     38.47701  1.00000     1.04651  1.00000
```

- Sum of individual Jo (numbers in red boxes) should equal the printout value in WRFDA log file, e.g., rsl.out.0000:

  Final value of Jo = 28880.81069

- Numbers in blue boxes are observation error tuning factors used in WRFDA:

  Tuned obs_error = obs_error * tuning_factor

  Where obs_error values are assigned by OBSPROC and tuning_factor=1 by default.

cost_fn and grad_fn

- Contains values of the cost function and its gradient.
  - If calculate_cg_cost_fn =.false., only the initial and final values of the cost and gradient functions are output as follows:

cost_fn

```
Outer    EPS     Inner          J          Jb            Jo          Jc          Je          Jp          Js          Jl
Iter             Iter
  1  0.100E-01     0     24322.148      0.000   24322.148      0.000      0.000      0.000      0.000      0.000
  1  0.100E-01    21  16141.945   1847.293  14294.652      0.000      0.000      0.000      0.000      0.000
```

grad_fn

```
Outer    EPS     Inner      G          Gb       Go          Ge          Gp          Gs              Gl
Iter              Iter
  1  0.100E-01     0    543.846      0.000    543.846      0.000      0.000      0.000        0.000
  1  0.100E-01    21      4.767     60.783     60.970      0.000      0.000      0.000        0.000
```

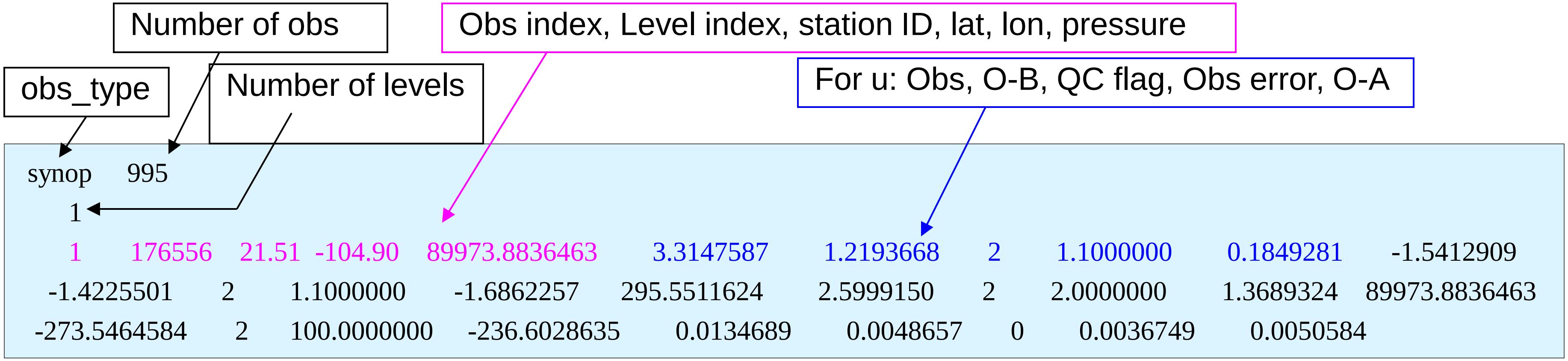
b: background term
o: observation term
c: JcDFI term
e: alpha term
p: radiance variational bias
correction term
s: skin temperature or
cloud cover term
l: lateral boundary
conditions control variable
(4dvar only)

- If calculate_cg_cost_fn =.true., the cost function and its gradient at each iteration will be computed and written into **cost_fn** and **grad_fn**.

✓ WRFDA tools: plot_cost_grad_fn.ncl

gts_omb_oma_01

- Contains complete point-by-point, detailed observation information.



Number of obs

obs_type

Number of levels

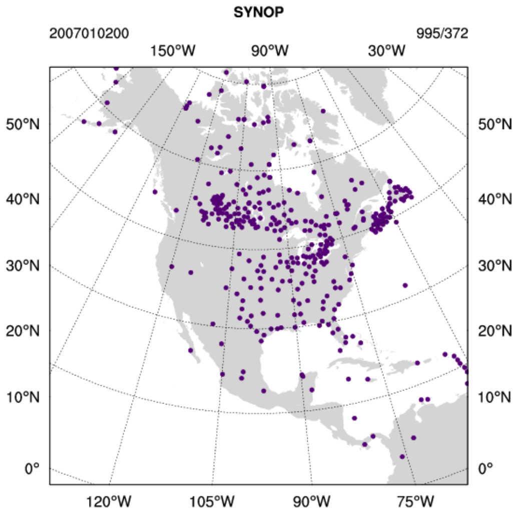
Obs index, Level index, station ID, lat, lon, pressure

For u: Obs, O-B, QC flag, Obs error, O-A

```
  synop    995
     1
     1      176556    21.51  -104.90    89973.8836463       3.3147587       1.2193668      2       1.1000000       0.1849281      -1.5412909
  -1.4225501       2       1.1000000       -1.6862257      295.5511624      2.5999150       2       2.0000000       1.3689324     89973.8836463
 -273.5464584      2       100.0000000      -236.6028635       0.0134689       0.0048657       0       0.0036749       0.0050584
```

- Measured quantities for each observation type vary:

synop: u, v, t, p, q
metar: u, v, t, p, q
ship: u, v, t, p, q
geoamv: u, v
airep: u, v, t
pilot: u, v
satem: thickness
qscat: u, v
polaramv: u, v
gpspw: tpw
sound: u, v, t, q
sonde_sfc: u, v, t, p, q
profiler: u, v
buoy: u, v, t, p, q
airsr: t, q
gpsref: ref



✓ WRFDA tools: plot_gts_omb_oma.ncl
✓ WRFDA tools: plot_ob_ascii_loc.ncl

statistics

- Contains domain-wide O-B and O-A information:

Diagnostics of OI for synop

```
   var          u (m/s)     n    k   v (m/s)     n    k    t (K)       n    k    p (Pa)      n    k    q (kg/kg)   n    k
 Number:            331                  332                  355                   330                  361
Minimum(n,k):      -5.4017  363    0    -5.4086  878    0    -9.7206  592    0  -390.7893  931    0 -0.4461E-02  719    0
Maximum(n,k):       5.0466  886    0     5.2878  630    0     7.7302  421    0   471.9343  944    0  0.5408E-02  787    0
Average    :     -0.8471             -0.1995              -1.1171               20.4177             -0.2525E-03
  RMSE     :      2.3023              2.1150               3.1978              116.1518              0.8045E-03
```

Diagnostics of AO for synop

```
   var          u (m/s)     n    k   v (m/s)     n    k    t (K)       n    k    p (Pa)      n    k    q (kg/kg)   n    k
 Number:            331                  332                  355                   330                  361
Minimum(n,k):      -4.2496  172    0    -5.0463  683    0    -8.9005  583    0  -472.9290  931    0 -0.4152E-02  719    0
Maximum(n,k):       5.5540  886    0     5.7990  630    0     8.8192  421    0   392.4096  944    0  0.5058E-02    1    0
Average    :     -0.0847             -0.0376              -0.4283                1.1709              0.1625E-04
  RMSE     :      1.8650              1.8093               2.1990              101.3816              0.5958E-03
```

Minimum of gridded analysis increments

```
Lvl      u     i    j        v     i    j        t    i    j        p     i    j        q     i    j
 1    -1.8915  17   32    -1.9965  36   24    -5.2526  20   35  -314.7470  44    1 -0.1451E-02  18   32
 2    -1.9476  16   32    -2.0070  36   24    -3.0142  21   36  -311.2885  44    1 -0.1438E-02  18   33
```

Maximum of gridded analysis increments

```
Lvl      u     i    j        v     i    j        t    i    j        p     i    j        q     i    j
 1     1.3750  41    8     1.5739  28   12     3.2994  24   20   197.8351  28    2  0.1401E-02  39    8
 2     1.4844  40    8     1.6180  28   13     1.7471   7   20   195.5165  28    2  0.1591E-02  39    8
```

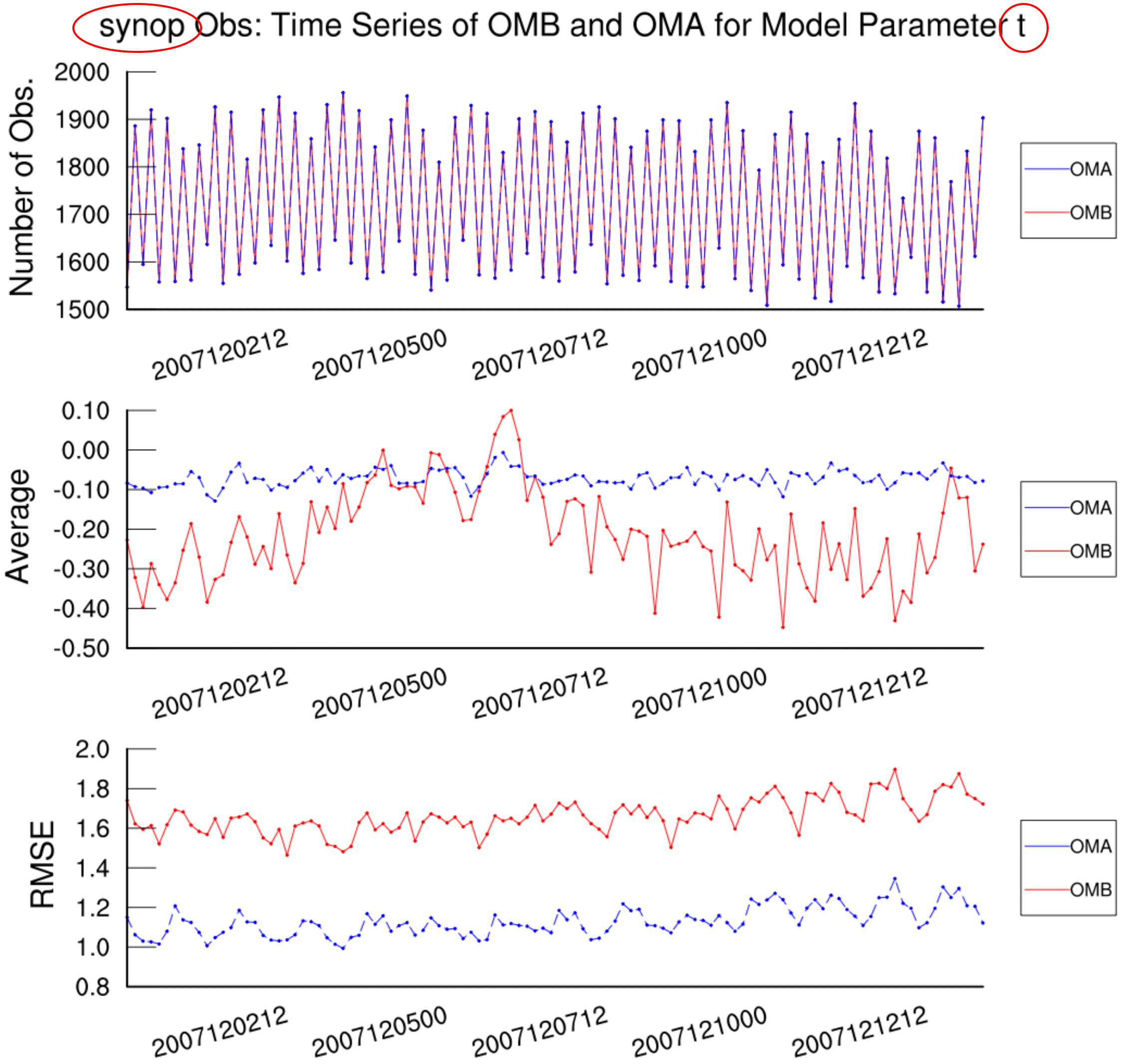
Mean of gridded analysis increments

```
Lvl      u          v          t          p          q
 1    -0.0327     0.0632    -0.1477    17.4414 -0.1047E-03
 2    -0.0031     0.0736     0.0116    17.2543 -0.8066E-04
```

RMSE of gridded analysis increments

```
Lvl      u          v          t          p          q
 1     0.7546     0.6040     1.3120    72.0441  0.4258E-03
 2     0.7995     0.6483     0.9169    71.2614  0.4476E-03
```

Information contained in **statistics** files can be used to plot time series of O-B and O-A for each observation variable and type.



Wrap-up

A Few Things I Didn’t Cover

- First-Guess at Appropriate Time (FGAT; &wrfvar3)
- Background error covariance tuning (&wrfvar7)
- Radiance assimilation (&wrfvar4, &wrfvar14)
- Pseudo-single observation tests (&wrfvar15, &wrfvar19)

WRFDA USERS PAGE

http://www.mmm.ucar.edu/wrf/users/wrfda/index.html

WRFDA USERS GUIDE

http://www.mmm.ucar.edu/wrf/users/wrfda/Docs/user_guide_V3.6/users_guide_chap6.htm

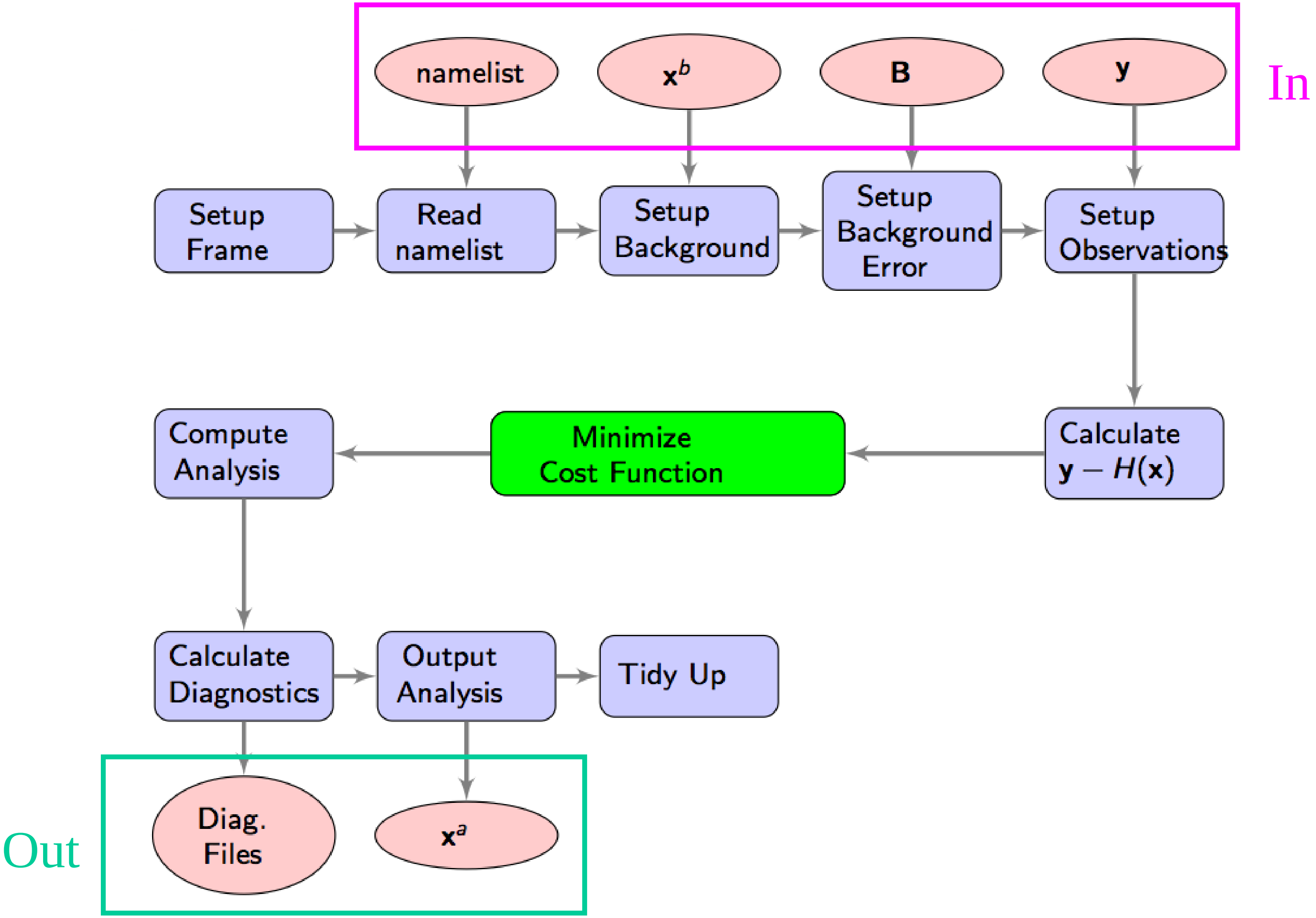
README files contained in the tar file

WRFDA/README.VAR
WRFDA/var/README.namelist
WRFDA/var/README.basics
WRFDA/var/README.radiance

wrfhelp@ucar.edu

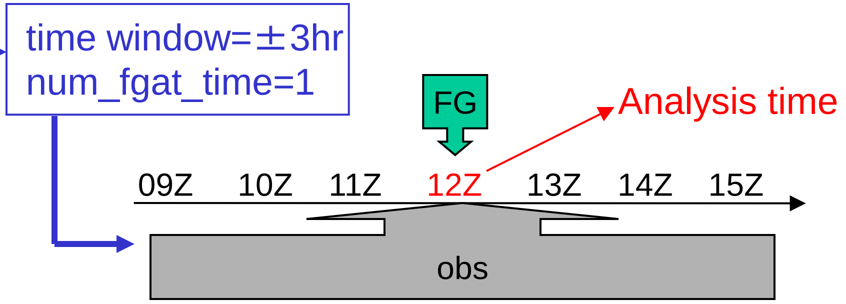
Extra Slides for your Reference

- **WRFDA Code Flow**



Namelist - WRFVAR3

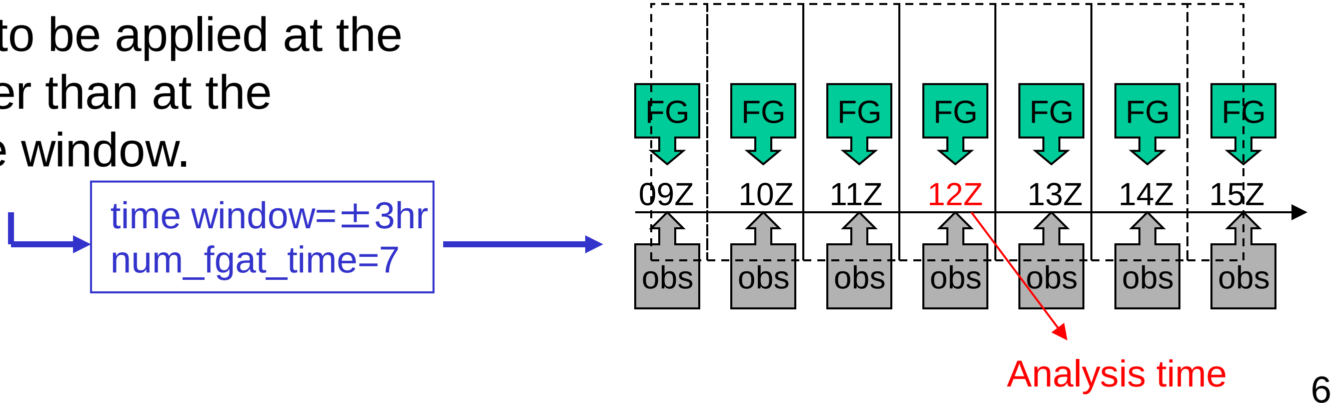
- num_fgat_time: Number of data time windows (slots) used in WRFDA.
  - 1 = 3DVAR: Default.
  - >1 apply to FGAT and 4D-Var (for ob_format = 2 and radiance only).



time window=±3hr
num_fgat_time=1

✓ **First-Guess at Appropriate Time (FGAT):**

An option in WRF-3DVar that allows the observations to be applied at the correct time, rather than at the middle of the time window.



time window=±3hr
num_fgat_time=7

Running WRFDA with FGAT

1. prepare hourly obs files using OBSPROC
2. prepare hourly first guess files from previous WRF forecasts
3. when running WRFDA-3DVar,
    - a) set num_fgat_time = 7 in namelist.input &wrfvar3
    - b) link hourly obs to be ob01.ascii, ob02.ascii, ..., ob07.ascii
    - c) link hourly first guess (previous WRF hourly forecasts) to be fg01, fg02, ..., fg07
    - d) link first guess valid at analysis time to be fg

OBSPROC

&record9 of namelist.3dvar_obs

```
&record9
  use_for='FGAT'
  num_slots_past=3
  num_slots_ahead=3
```

WRF model

add the following settings (write_input, inputout_interval, input_outname, inputout_begin_h, inputout_end_h) in &time_control of namelist.input

```
&time_control
   write_input       = .true.
   inputout_interval = 60
   input_outname     = 'wrfinput_d<domain>_<date>'
   inputout_begin_h  = 3
   inputout_end_h    = 9
```

WRFDA-3DVar

&wrfvar3 record of namelist.input

```
&wrfvar3
       num_fgat_time = 7

ln -sf obs_gts_2007-01-01_21:00:00.FGAT  ob01.ascii
ln -sf obs_gts_2007-01-01_22:00:00.FGAT  ob02.ascii
ln -sf obs_gts_2007-01-01_23:00:00.FGAT  ob03.ascii
ln -sf obs_gts_2007-01-02_00:00:00.FGAT  ob04.ascii
ln -sf obs_gts_2007-01-02_01:00:00.FGAT  ob05.ascii
ln -sf obs_gts_2007-01-02_02:00:00.FGAT  ob06.ascii
ln -sf obs_gts_2007-01-02_03:00:00.FGAT  ob07.ascii

ln -sf wrfinput_d01_2007-01-01_21:00:00  fg01
ln -sf wrfinput_d01_2007-01-01_22:00:00  fg02
ln -sf wrfinput_d01_2007-01-01_23:00:00  fg03
ln -sf wrfinput_d01_2007-01-02_00:00:00  fg04
ln -sf wrfinput_d01_2007-01-02_01:00:00  fg05
ln -sf wrfinput_d01_2007-01-02_02:00:00  fg06
ln -sf wrfinput_d01_2007-01-02_03:00:00  fg07

ln -sf wrfinput_d01_2007-01-02_00:00:00  fg
```