WRFDA-3DVar Setup, Run and Diagnostics

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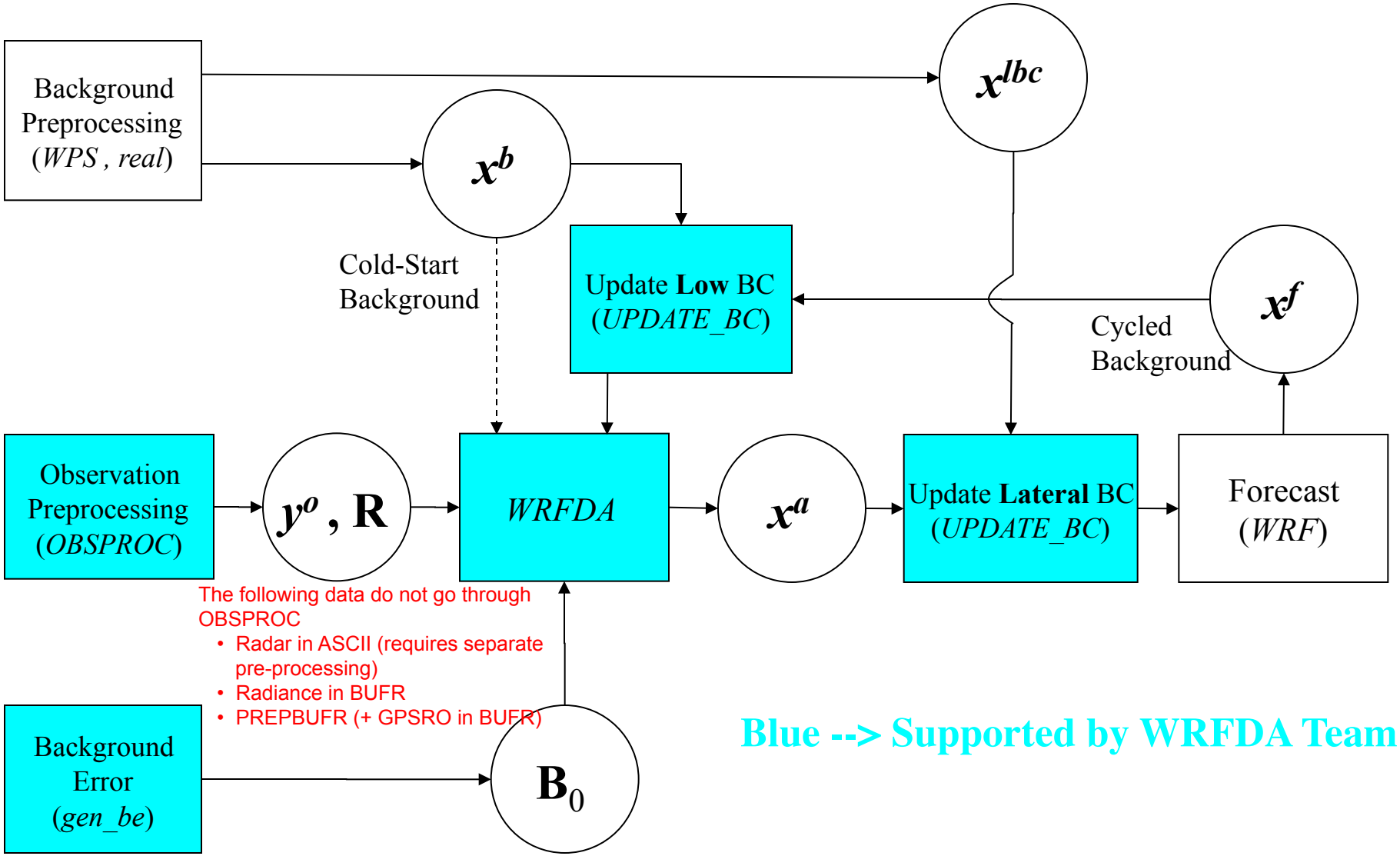
• WRFDA in the WRF Modeling System



Outline

- Installing WRFDA-3DVar
- Running WRFDA-3DVar code
- Running UPDATE_BC
- WRFDA-3DVar diagnostics
- Basic runtime options (namelist)

This talk is tailored based on WRFDA V3.2

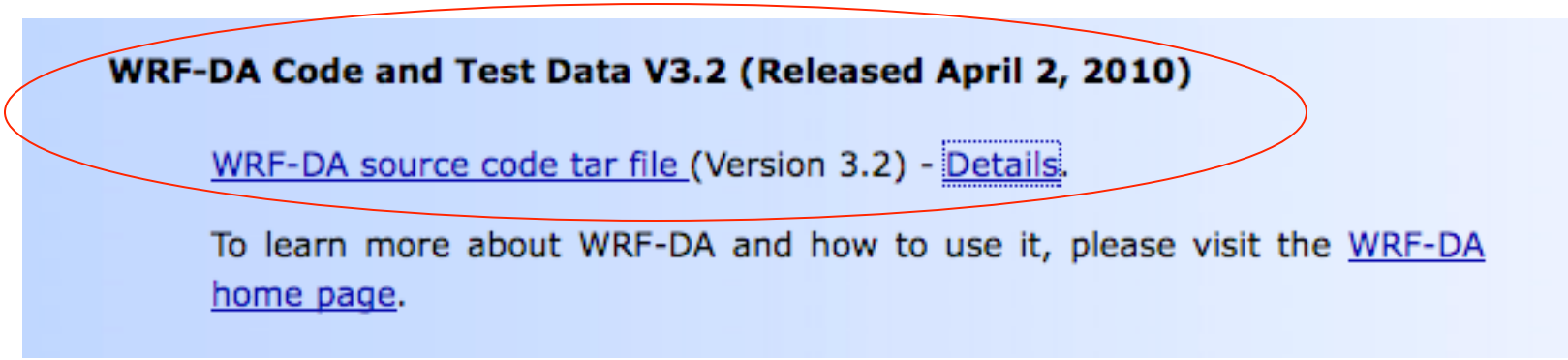
Installing WRFDA
3D-Var

Source Codes

- Download WRF-Var source code (WRFDAV3.2.TAR.gz) from

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

After following the instruction from the above URL, on the actual download page, look for



FORTRAN 90 Compiler

Supported and tested platforms

- IBM with XLF
- Intel Mac with PGI and G95 (GCC 4.0.3 (g95 0.91!) Sep 12 2007)
- Linux i686 with PGI, INTEL and GFORTRAN (gcc version 4.3.3 20090123 or newer)

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

Supported but tested by a 3rd party

- SGI Altix with ifort
- cray with ftn 6.0.0.2.1

Unsupported platforms

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

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

Does not work on

- PGI 5.x
- Windows

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

Libraries Required by WRFDA

- **NetCDF**: Network Common Data Form

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

- BLAS: Basic Linear Algebra Subprograms

  http://netlib.org/blas/

- LAPACK: Linear Algebra PACKage

  http://netlib.org/lapack/

Included in WRFDA (as of V3.1.1):

WRFDA/var/external

Set environment variables:

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

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

Optional Libraries

- If using PREPBUFR data 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_1.2)

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

    ✓ Link $CRTM/libcrtm.a to $CRTM/src/libCRTM.a
  - **RTTOV**: Radiative Transfer for TOVS (version 8.7)

    http://www.metoffice.gov.uk/science/creating/working_together/nwpsaf_public.html

    ✓ Link $RTTOV/librttov.a to $RTTOV/src/librttov8.7.a

Set environment variables:

```
> setenv BUFR  1
> setenv CRTM  $your_installation_dir/crtm
> setenv RTTOV $your_installation_dir/rttov
```

Optional Libraries

- If using PREPBUFR data 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_**2.0.2**)

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

    CRTM will be included in WRFDA V3.2.1 release (summer 2010)
  - RTTOV: Radiative Transfer for TOVS (version 8.7)

    http://www.metoffice.gov.uk/science/creating/working_together/nwpsaf_public.html

    ✓ Link $RTTOV/librttov.a to $RTTOV/src/librttov8.7.a

Set environment variables:

```
> setenv BUFR  1
> setenv CRTM  1
> setenv RTTOV $your_installation_dir/rttov
```

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

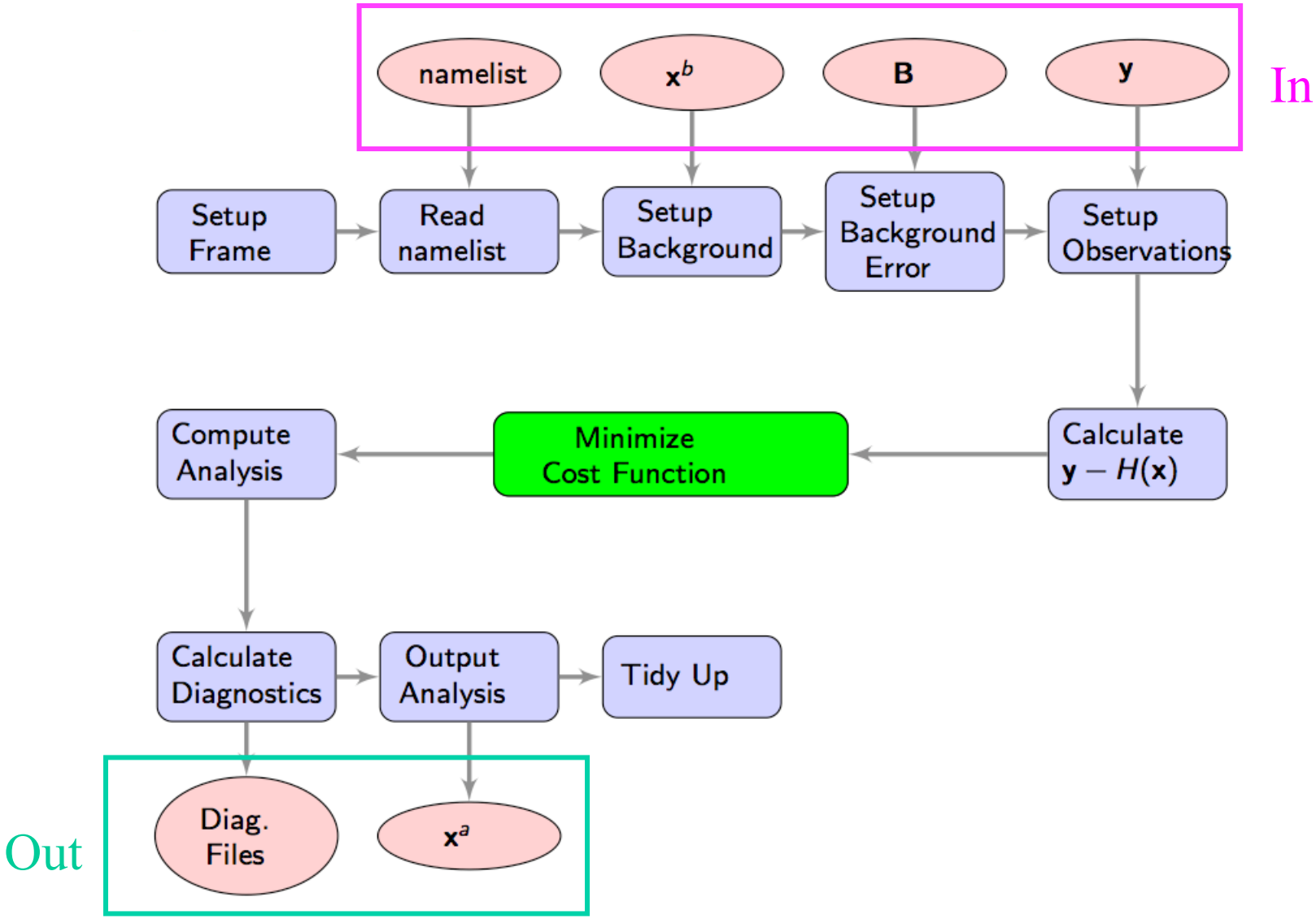
> **`./compile all_wrfvar`**
  - 31 executables in the var/build (linked to var/da):
    - da_wrfvar.exe: WRFDA
    - da_updated_bc.exe: update_bc
    - gen_be_stage0_wrf.exe, …: gen_be
    - da_advance_time.exe: time manipulation
  - OBSPROC executable in the var/obsproc/src
    - obsproc.exe: OBSPROC
- Clean the WRFDA directory before making your next compilation:

```
> clean -a
```

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

Running WRFDA
3D-Var

- **WRFDA Code Flow**



Before You Run …

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

- Get input files:
  - The test data (WRFDAV3.2-testdata.tar.gz) can be downloaded from http://www.mmm.ucar.edu/wrf/users/wrfda/download/testdata.html

  - Extract the test data into your local data directory, e.g., "*your_choice_of_dat_dir*".

  - Set up your environment variable $DAT_DIR:

    `> setenv DAT_DIR` *`your_choice_of_dat_dir`*

Before You Run …

- Check input files:
  - Background ($\boldsymbol{x}^b$): $DAT_DIR/rc/2008020512/wrfinput_d01
    - NETCDF format.
    - For cold-start mode, $\boldsymbol{x}^b$ is generated by WRF *real*.
    - For cycling mode, $\boldsymbol{x}^b$ is generated by WRF from previous cycle (e.g., 6hr forecast).
  - Background Error Statistics: $DAT_DIR/be/be.dat
    - Binary format.
    - Generated by *gen_be* for this specific test case domain.
    - Please refer to *"**WRFDA Background Error Estimations**"* talk.
  - Observations ($\boldsymbol{y}^o$) : $DAT_DIR/ob/2008020512/ob.ascii (GTS data only)
    - ASCII format.
    - Generated by OBSPROC from obs.2008020512.gz included in the tar file of the test data.
    - Please refer to "**Radar Data Assimilation**" and "**Radiance Data Assimilation**" talks for assimilations of radar and radiance data.
- Prepare a WRFDA namelist for runtime options:
  - WRFDA/var/test/tutorial/namelist.input (example)

Working Directory - Input

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

```
> mkdir 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/2008020512/wrfinput_d01  ./fg
> ln -sf $DAT_DIR/be/be.dat                  ./be.dat
> ln -sf $DAT_DIR/ob/2008020512/ob.ascii     ./ob.ascii
> cp WRFDA/var/test/namelist.input        ./namelist.input
```

(or use your own namelist)

- To run WRFDA with ob.ascii (observations preprocessed by obsproc)

```
ln  –sf  output_from_obsproc  ob.ascii

&wrfvar3
   ob_format = 2
```

- To run WRFDA with NCEP PREPBUFR file

```
ln  –sf  ncep_prepbufr_file   ob.bufr

&wrfvar3
   ob_format = 1
```

Running WRFDA

> **`./da_wrfvar.exe >&! wrfda.log`** (or your own log file name)

> **`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

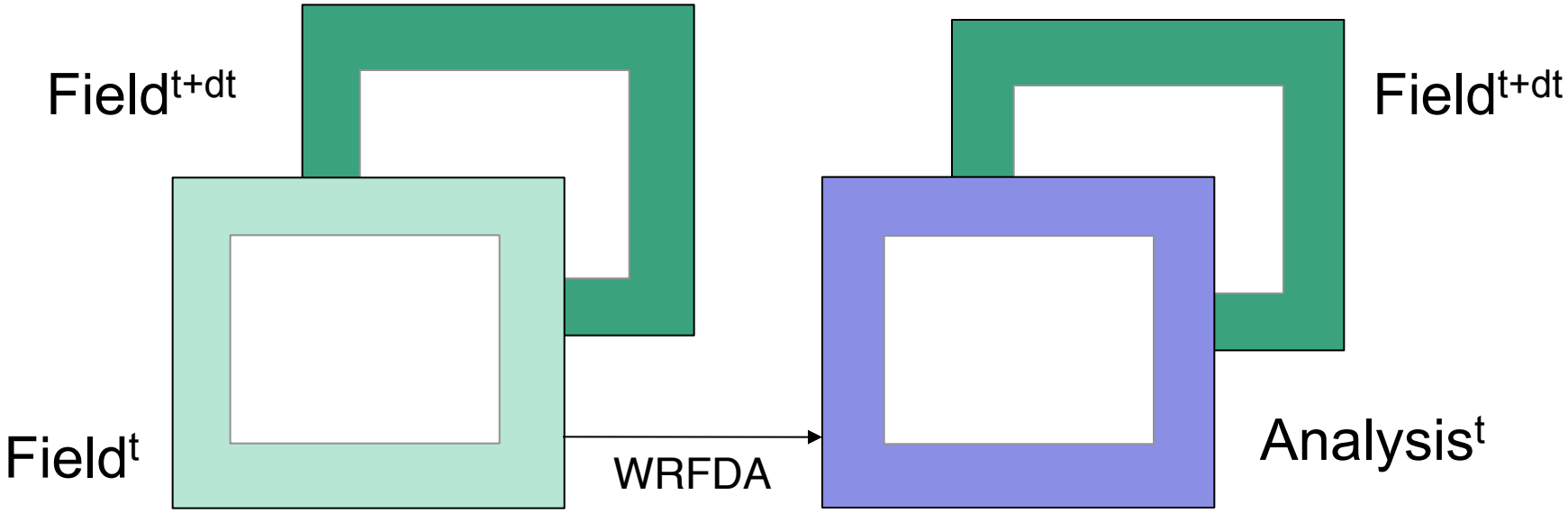
In *your_choice_of_working_dir*, you should at least have the following files after WRFDA is successfully completed:

- 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-wise O-B and O-A statistics)
- **wrfvar_output (Analysis x^a,** the input to WRF model**)**

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

“update_bc” Basic

Why do we need update_bc?
(update **lateral** boundary for domain **1**)



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

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

Why do we need update_bc?
(update **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
- **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

Applications of update_bc

- Cold-start run

  only lateral boundary update needed

- Warm-start (cycling) run

  both lateral and low boundaries updates needed

- Coarse and fine domains in nested model run

  - for coarse domain (domain_id = 1),

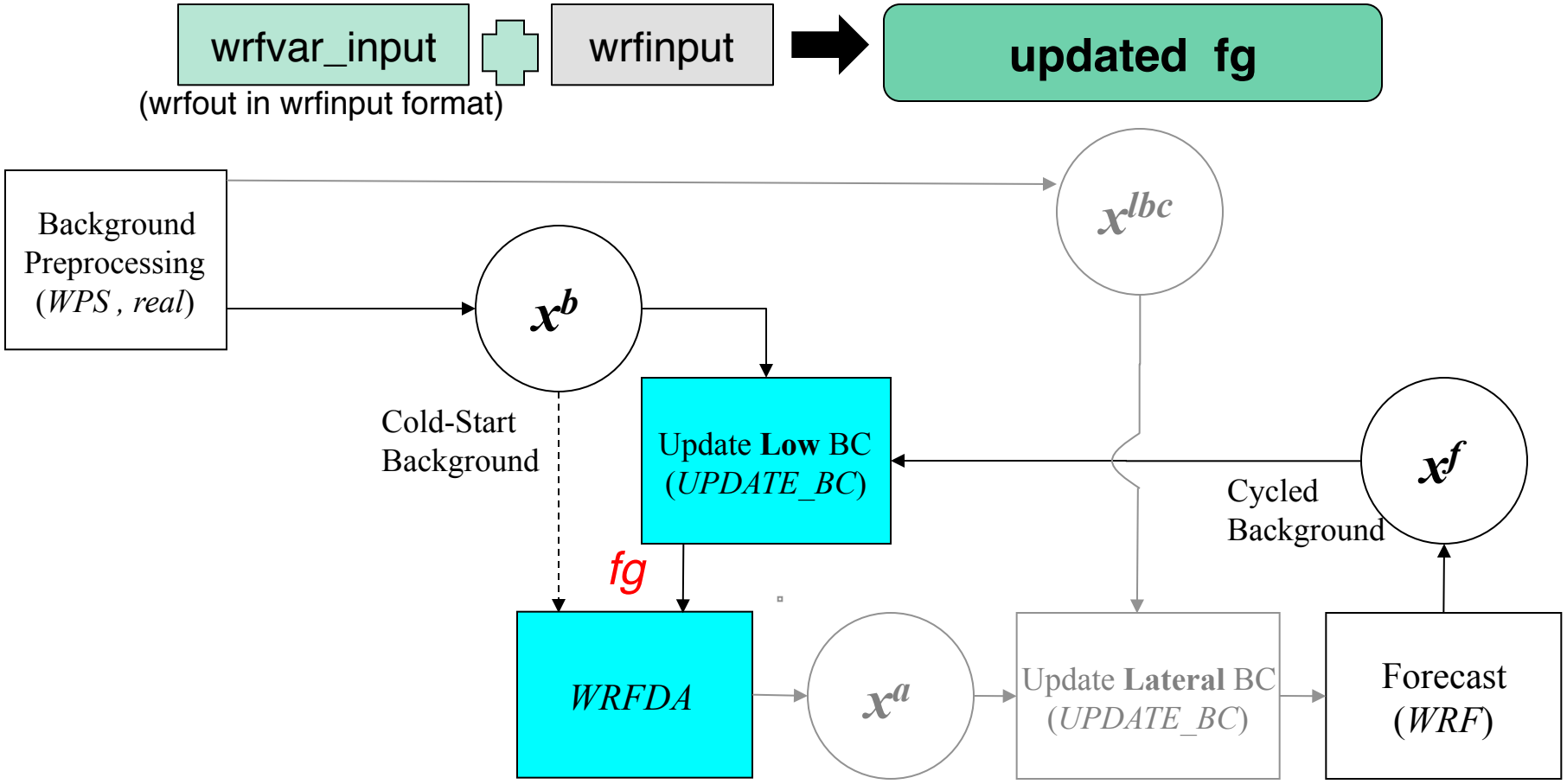
    both lateral and low boundaries updated

  - for fine mesh domains (domain_id > 1),

    low boundary updated only

Running update_bc

update_bc (low boundary condition)



- If in cold-start mode, there is no need to update low BC
- If in cycling mode, update **low** BC **before** running WRFDA

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:

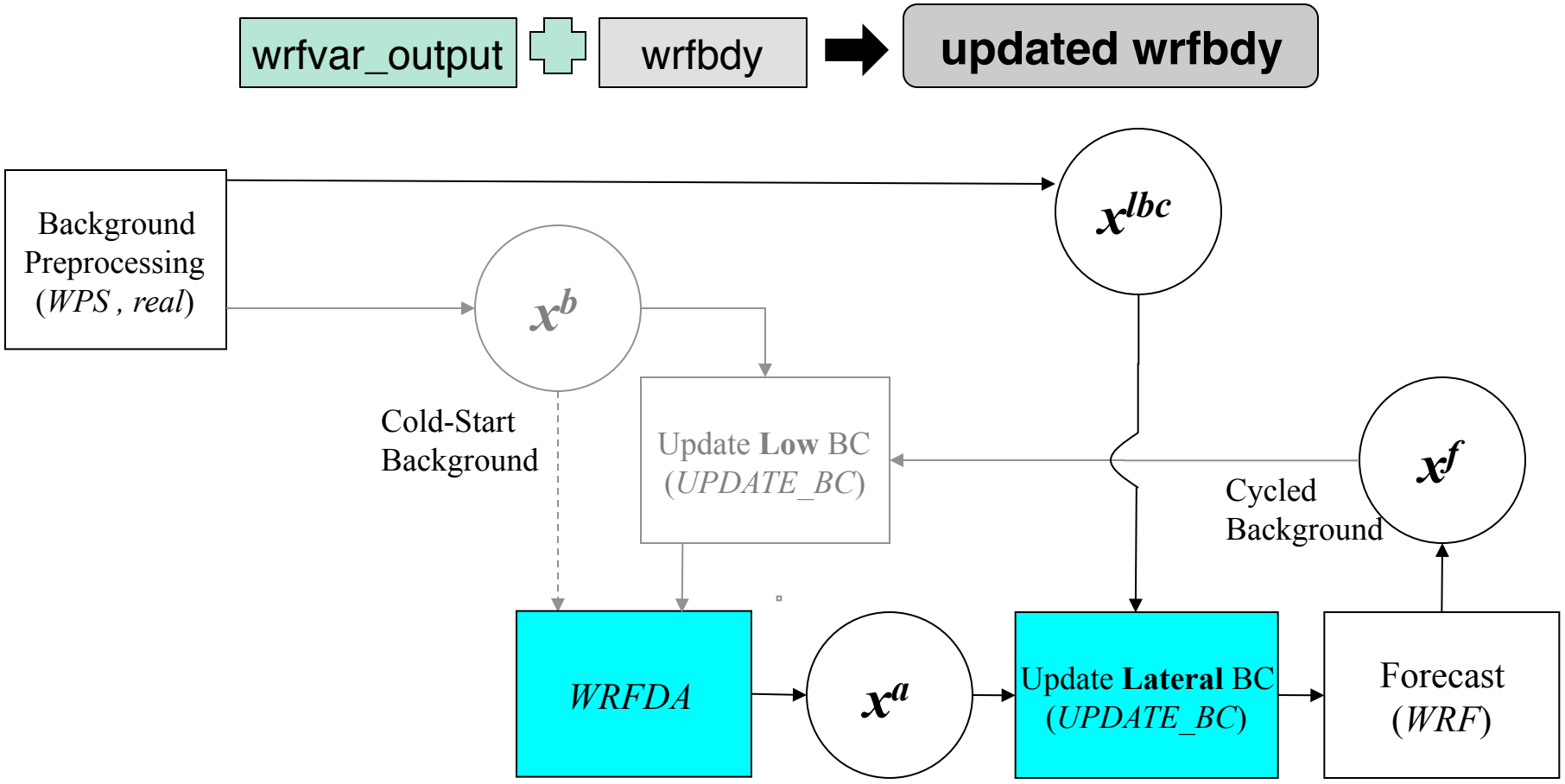
```
> cd your_choice_of_working_dir
> cp ${your_wrf_run_dir}/wrfvar_input_d01   ./fg
> ln –sf WRFDA/var/build/da_update_bc.exe   ./da_update_bc.exe
```

- 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/2008020512/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`

update_bc (lateral boundary condition)



- If domain 1, update **lateral** BC **after** running WRFDA

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/2008020512/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`

WRFDA-3DVar Diagnostics

ASCII output files in the WRFDA working directory:

- wrfda.log or rsl.out.0000
- namelist.output
- filtered_obs (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

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 (Using these options, the log file size could become really 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 will be 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

- Similar to ob.ascii (observation input file of WRFDA) but it contains the observations filtered by WRFDA
- To have the file outputted, set WRFDA namelist option: analysis_type = “QC-OBS”
- 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 model 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.
  - ✓ 01: outer loop index.
  - ✓ 000: processor id.

- Observations are rejected if the innovation (O-B) values are larger than certain maximum values defined as a multiple of the observation error for each observation (obs_error*factor). The default maximum value is 5 times the observation error. the factor of 5 can be changed through max_error_* namelist settings.

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 internal QC (e.g, check_max_iv check).
  - ✓ 01: outer loop index.

WRF-Var data utilization statistics for outer iteration 1

obs type	var		ptop 1000.0 pbot 1200.0	900.0 999.9	800.0 899.9	600.0 799.0	400.0 599.9	300.0 399.9	250.0 299.9	200.0 249.9	150.0 199.9	100.0 149.9	50.0 99.9	0.0 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

cost_fn and grad_fn

- Contain values of cost function and its gradient at each iteration.
  - If print_detail_grad=.false., only the initial and final values of the cost and gradient functions are output as follows:

cost_fn

Outer Iter	EPS	Inner Iter	J	Jb	Jo	Jc	Je	Jp	Js
1	0.100E-01	0	24322.148	0.000	24322.148	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

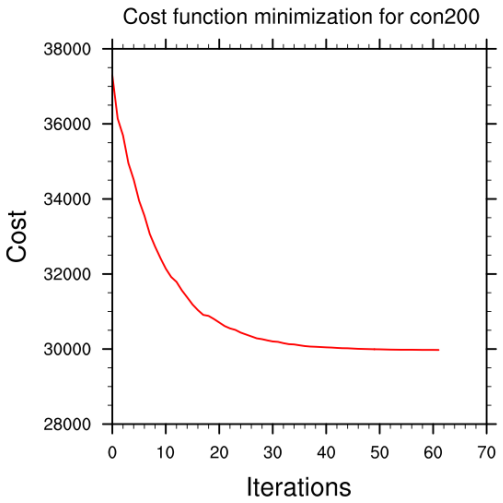
grad_fn

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

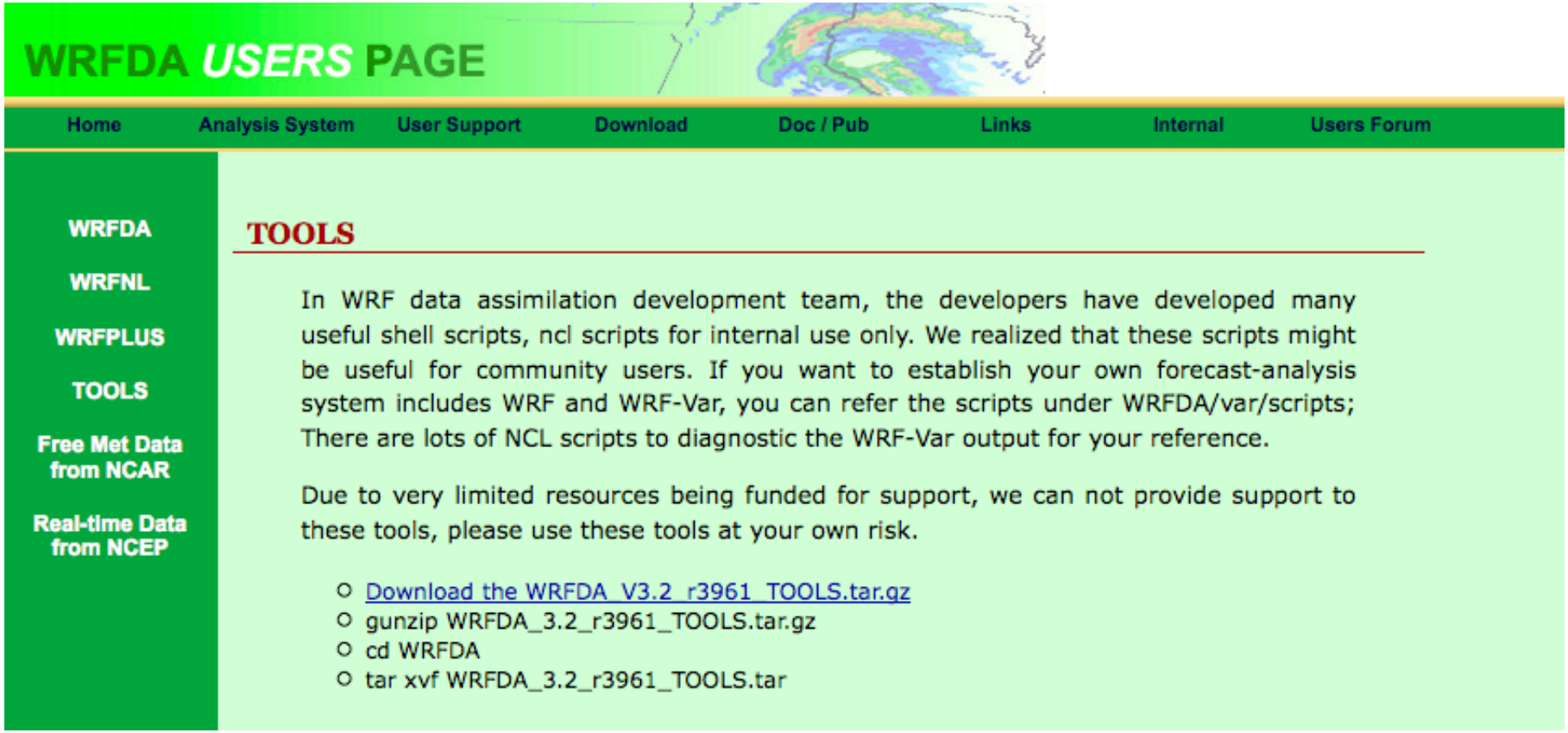
b: background term
o: observation term
c: JcDFI term
e: alpha term
p: radiance variational bias correction term
s: skin temperature or cloud cover term

  - If print_detail_grad=.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* (see the next slide)



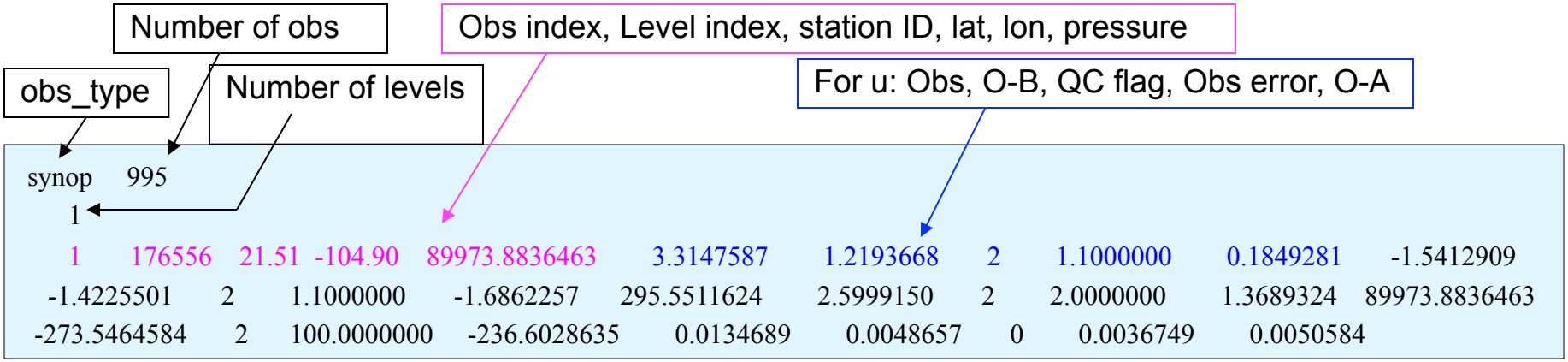
http://www.mmm.ucar.edu/wrf/users/wrfda/download/tools.html



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

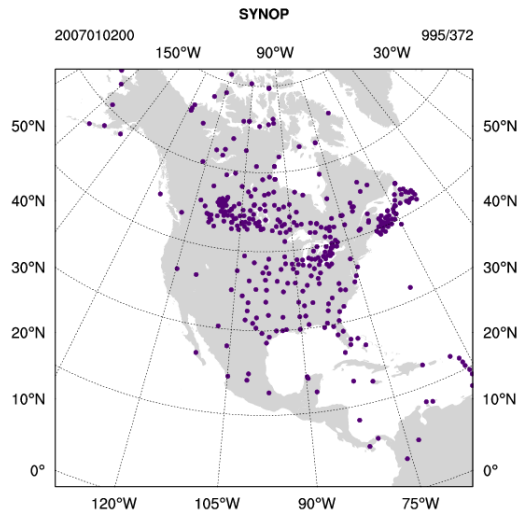
gts_omb_oma_01

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



- Measured quantities for each observation type vary:

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



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

statistics

- Contains domain-wise 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

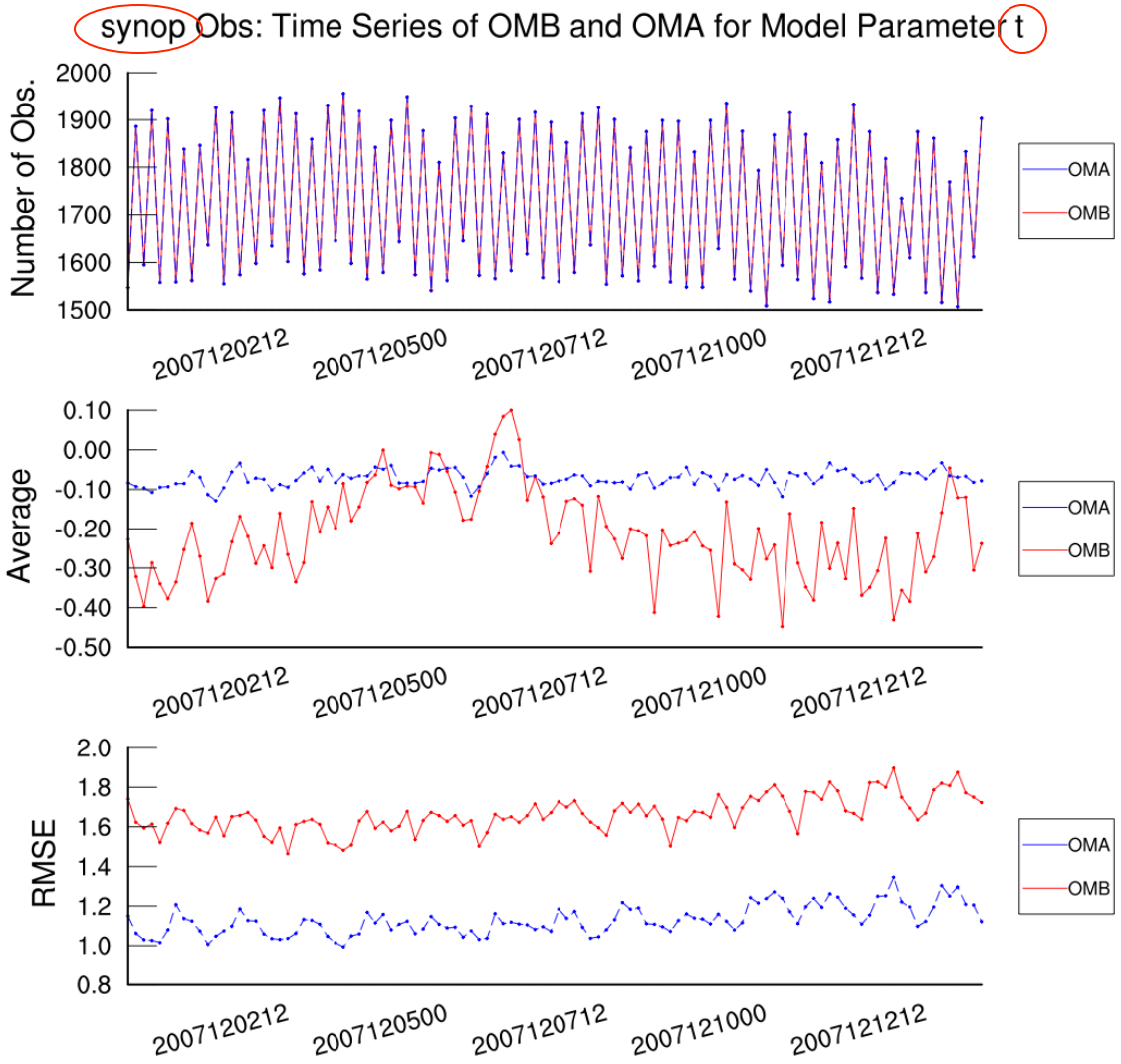
Mean of gridded analysis increments

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, O-A for each observation variable and type.



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 be equal to 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 factor=1 by default (use_obs_errfac=false).

WRFDA Running Options - Namelist

- ✓ The namelist mentioned in the following slides refer to 3D-Var runs and conventional data assimilation only. Please refer to specific lectures (BE, radiance, …) for other namelist options .

What is a Namelist?

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

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

- Description of WRFDA namelist variables are given in WRF User's Guide and README.namelist in the release tar file (**WRFDA/var/README.namelist**).

WRFDA Namelist

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

```
&wrfvar1
/
&wrfvar2
/
…
&wrfvar23
/
&time_control
/
&fdda
/
…
&namelist_quilt
/
```

WRFDA namelist options:
Running options for WRFDA code.

WRF namelist options:
WRFDA needs certain information from this file including domain and time setting. Please make sure this part of the namelist file is consistent with the namelist used in your WRF *real* and WRF runs.

Namelist - WRFVAR1

- print_detail_grad
  - .false. : Default
  - .true. : Output cost function gradient values of each observation type at each iteration into standard output files (rsl.out) and cost function and gradient values at each iteration into the files called “cost_fn” and “grad_fn”.

Outer Iter	EPS	Inner Iter	J	Jb	Jo	Jc	Je	Jp
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

Outer Iter	EPS	Inner Iter	J	Jb	Jo	Jc	Je	Jp
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

Namelist - WRFVAR2

- analysis_accu
  - 900 (Sec): Default.

  If |analysis time - first guess time| > Analysis_accu, WRFDA will give a warning like "*Wrong xb time found???*", but won't abort.

  ✓ Make sure the time of the first guess file matches the analysis time.

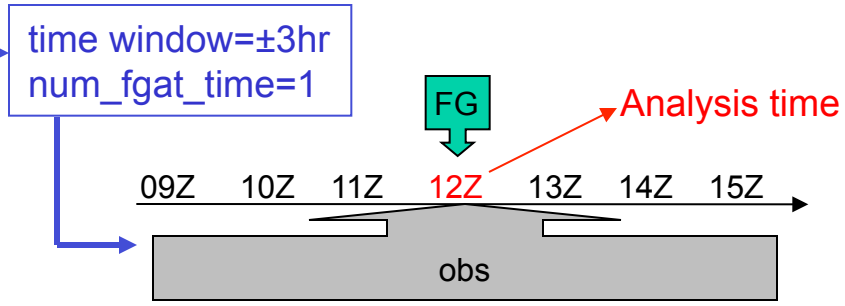
Namelist - WRFVAR3

- fg_format: Format of the first guess of WRFDA
  - 1 = ARW regional: Default
  - 2 = WRF-NMM regional (not tested)
  - 3 = ARW global (not tested)
  - 4 = KMA global (not tested)

- ob_format: The format of the conventional and satellite retrieval observation data going into WRFDA
  - 1 = NCEP PREPBUFR (ob.bufr) (gpsro.bufr)
  - 2 = ASCII (ob.ascii): Default
  - 3 = MADIS data format (not tested)

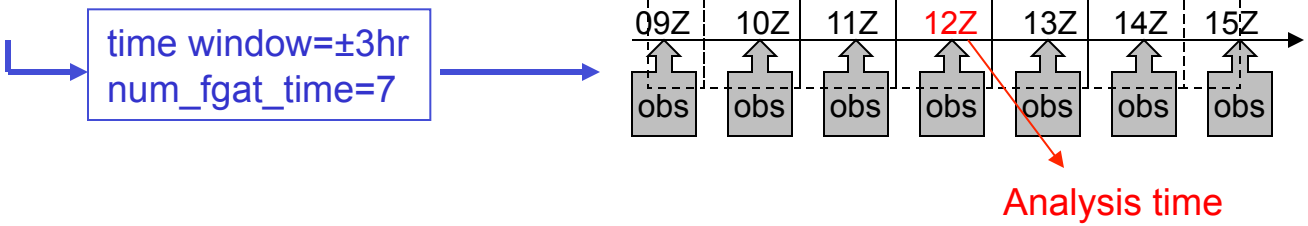
Namelist - WRFVAR3

- 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).



✓ **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.



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 namelistinput

```
&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
```

Namelist - WRFVAR4

- thin_conv
  - .true.: Default. Mandatory for ob_format=1 (NCEP PREPBUFR) to avoid time duplication.
  - .false. Used only for debugging purpose.

- thin_mesh_conv (max_instruments): Thinning mesh for each type of conventional observations. This option is used for ob_format=1 (NCEP PREPBUFR) only. The observation index/order follows the definition in WRFDA/var/da/da_control/da_control.f90 (e.g., sound =1, synop =2, …)
  - 20.0 (km): Default.

Namelist - WRFVAR4

- use_xxxobs: Set to true to use particular observation types.
  - e.g, use_gpsrefobs=.true.: Assimilate GPS refractivity observations if gpsref data are available in the data file.

  xxx: synop, ships, metar, sound, pilot, airep, geoamv, polaramv, buoy, profiler, satem, gpspw, gpsref, qscat, radar, airsret, hirs2, hirs3, hirs4, mhs, msu, amsua, amsub, airs, eos_amsua, hsb, ssmis

- use_obs_errfac: Option for using tuned observation error (conventional data only).
  - .false. : Default.
  - .true. : Use tuned observation error statistics (a file errfac.dat needs to be created beforehand by using da_tune_obs_desrozier.f).

Namelist - WRFVAR5

- check_max_iv: Options for rejecting the observations whose innovations (O-B) are larger than a maximum value defined as a multiple of the observation error for each observation. i.e., when O-B > (obs_error*factor), then fails_error_max. The default maximum value is 5 times the observation error. The factor of 5 can be changed through max_error_* settings.
  - .true. : default
  - .false: Use this option only if the observation data are known to have good quality.

- max_error_t (uv, pw, ref, q, …): maximum error factor allowed in check_max_iv check for t (u/v, pw, ref, q, …).

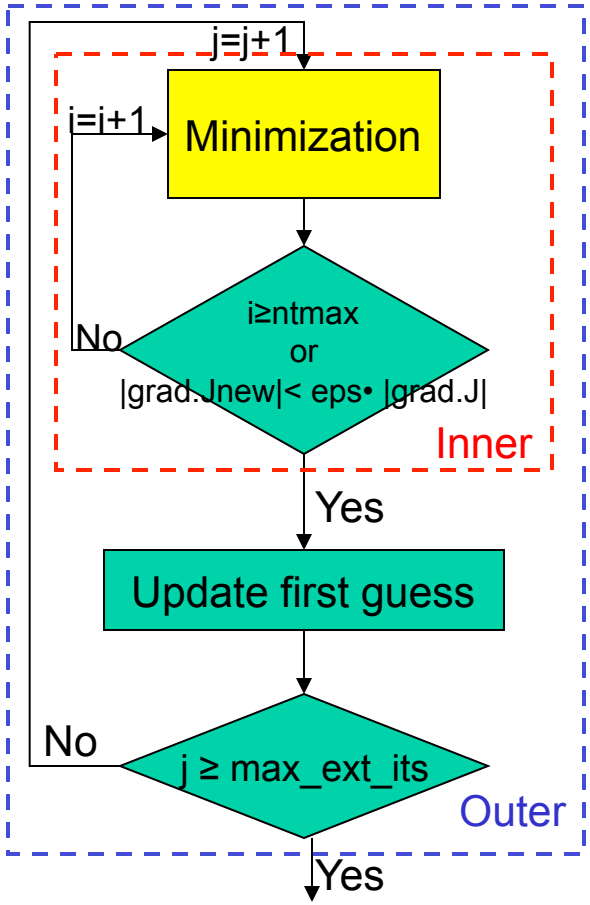
Namelist - WRFVAR6

The following namelist variables are for minimization options:

- max_ext_its: Number of outer loops.
  - 1: Default. Only one outer loop.
  - allowed maximum outer loop number is 10, while common application is 2.

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

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



Namelist - WRFVAR11

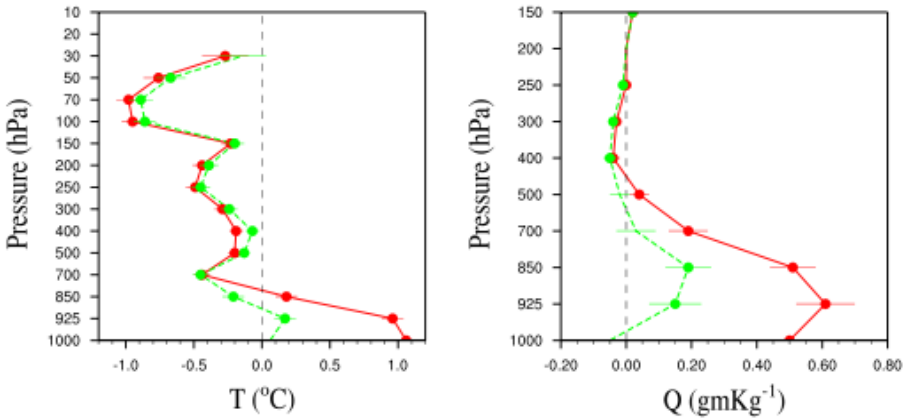
- cv_options_hum:
  - 1 (default): Please do not change.

- check_rh*:
  - 0: No supersaturation check after minimization.
  - 1: With the supersaturation (rh> 100%) and minimum rh (rh<10%) check, and make the local adjustment of q.
  - 2 (default): With the supersaturation (rh> 95%) and minimum rh (rh<11%) check, and make the multi-level q adjustment under the constraint of integrated water vapor in column conserved.

Namelist - WRFVAR11

- 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 100m.
  - 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.



Namelist - WRFVAR11

- calculate_cg_cost_fn:
  - .false.(default) : Only the initial and final cost functions are computed and output.
  - .true. : The cost functions are derived and output into standard output files (rsl.out) at every iteration for diagnostic purpose.

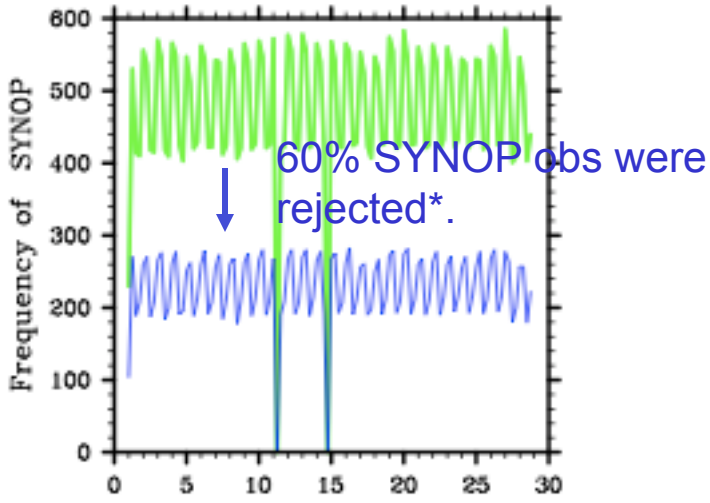
  ✓ The conjugate gradient algorithm for the minimization does not require the computation of cost function at every iteration.

  ✓ Set print_detail_grad=.true. (in &wrfvar1) to compute and output cost function and gradient values at every iteration into “cost_fn” and “grad_fn”.

Namelist - WRFVAR17

- analysis_type: Indicate job type of WRFDA.
  - 3D-VAR (default): Run 3D-Var data assimilation.
  - RANDOMCV: for creating ensemble perturbations.
  - VERIFY: Run WRFDA verification mode (check_max_iv=.false. and ntmax=0 by default).
    - ✓ Please refer to "**WRFDA Tools and Verification package**" talk.
  - QC-OBS: Run 3D-Var data assimilation and produce filtered_obs.
    - ✓ By combining with check_max_iv=.true. and ntmax=0, you can produce a WRFDA filtered (QCed) observation data set (filtered_obs) without running the data assimilation.

- 1st screen/QC procedure performed by observation preprocessor (OBSPROC).
- 2nd screen/QC procedure performed in WRFDA.
- Main impact of 2nd screen/QC is on surface observations*.
- Rejection rates will reduce with higher resolution, higher-order interpolation.



* Surface observation rejection here is mostly due to surface elevation check with sfc_assi_options=1.

Namelist - WRFVAR18

- analysis_date: Specify the analysis time. It should be consistent with the first guess time.

  ✓ If time difference between analysis_date and date info read in from first guess is larger than analysis_accu, WRFDA will issue a warning message "Wrong xb time found???", but won't abort.

Namelist - WRFVAR21/22

- time_window_min(max): Specify the lower (upper) time values of the assimilation time window.

  ✓Observations between time_window_min and time_window_max will be processed.

List of some namelist variables that are most likely to be user-modified (for conventional observations)

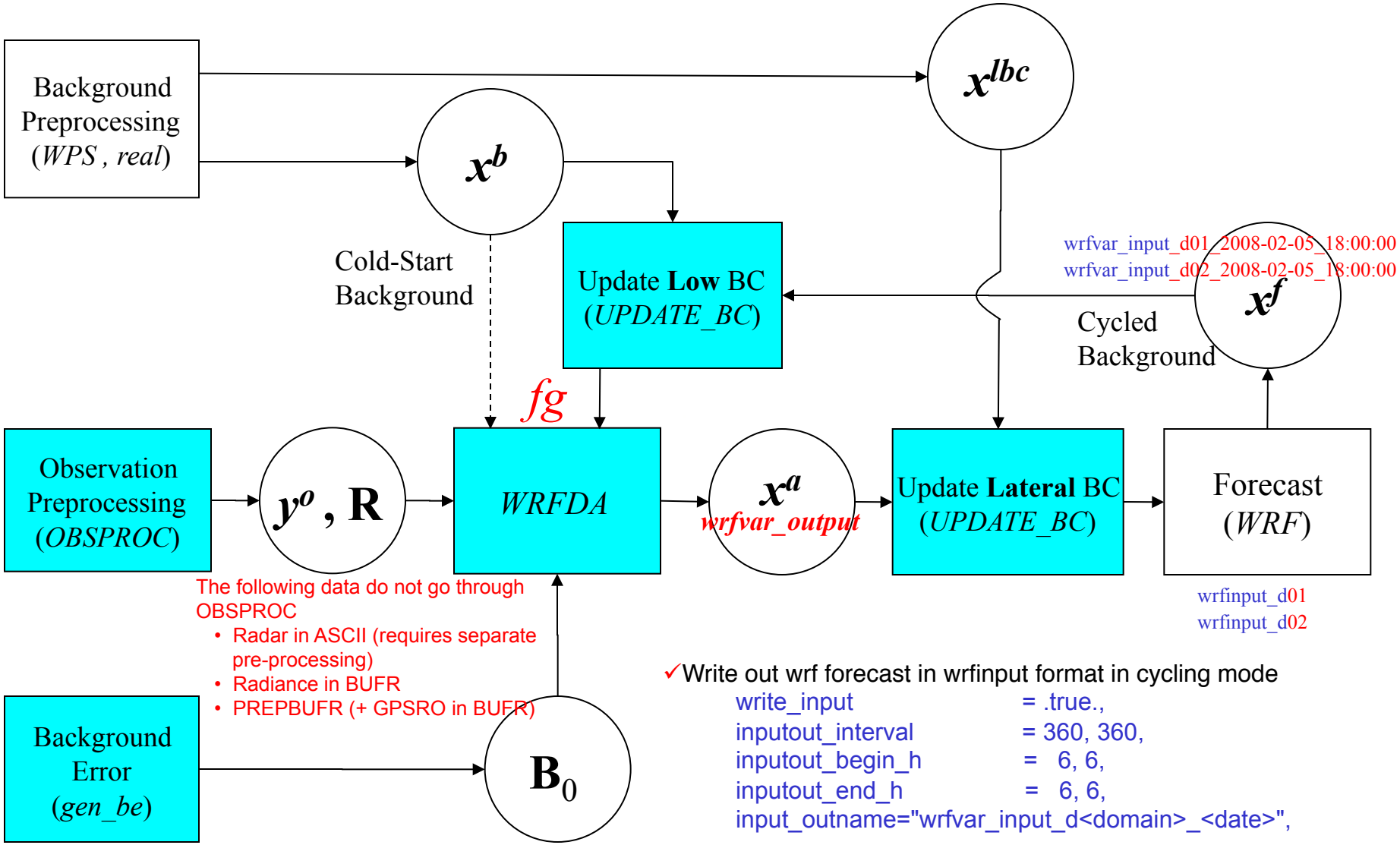
```
&WRFVAR1
 PRINT_DETAIL_GRAD = F,
&WRFVAR3
 FG_FORMAT = 1,
 OB_FORMAT = 2,
 NUM_FGAT_TIME = 1
&WRFVAR4
 THIN_CONV =  T,
 THIN_MESH_CONV = 30*20.0
 USE_SYNOPOBS =  T,
 USE_SHIPSOBS =  T,
 USE_METAROBS =  T,
 USE_SOUNDOBS =  T,
 USE_PILOTOBS =  T,
 USE_AIREPOBS =  T,
 USE_GEOAMVOBS =  T,
 USE_POLARAMVOBS =  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 &wrfvar23 to create a complete/ consistent namelist.input for WRFDA

• WRFDA in the WRF Modeling System



✓Write out wrf forecast in wrfinput format in cycling mode

```
write_input                 = .true.,
inputout_interval           = 360, 360,
inputout_begin_h            =   6, 6,
inputout_end_h              =   6, 6,
input_outname="wrfvar_input_d<domain>_<date>",
```

✓WRFDA processes only one domain at a time

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_V3.2/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