

USERS' GUIDE FOR RADIANCE DATA ASSIMILATION IN WRF-VAR

Zhiquan Liu, Tom Auligne and Hui-Chuan Lin
NCAR/MMM

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Introduction

This users guide gives brief description for various aspects related to radiance assimilation in WRF-Var. Each aspect is described mainly from the viewpoint of usage rather than more technical and scientific details, which will appear in separated technical report and scientific paper. Namelist parameters controlling different aspects of radiance assimilation will be detailed in the following sections. Note that this users guide does not cover general aspects of WRF-Var assimilation, which can be found in public released WRF-Var documentations.

Radiance Data Ingest

Currently, the ingest interface for NCEP BUFR radiance data is implemented in WRF-Var. The radiance data are available through NCEP's public ftp server `ftp://ftp.ncep.noaa.gov/pub/data/nccf/com/gfs/prod/gdas.$ {yyyymmddhh}` in near real-time (with 6-hour delay) and can meet requirements both for research purposes and some real-time applications.

So far, WRF-Var can read data from the NOAA ATOVS instruments (HIRS, AMSU-A, AMSU-B and MHS), the EOS Aqua instruments (AIRS, AMSU-A) and DMSP instruments (SSMIS). Note that NCEP radiance BUFR files are separated by instrument names (i.e., each file for one type instrument) and each file contains global radiance (generally converted to brightness temperature) within 6-hour assimilation window from multi-platforms. During WRF-Var running, users need to rename NCEP corresponding BUFR files (table 1) to **hirs3.buf**r (including HIRS data from NOAA-15/16/17), **hirs4.buf**r (including HIRS data from NOAA-18, METOP-2), **amsua.buf**r (including AMSU-A data from NOAA-15/16/18), **amsub.buf**r (including AMSU-B data from NOAA-15/16/17), **mhs.buf**r (including MHS data from NOAA-18 and METOP-2), **airs.buf**r (including AIRS and AMSU-A data from EOS-AQUA) and **ssmis.buf**r (SSMIS data from DMSP-16, AFWA provided) for WRF-Var filename convention. Note that **airs.buf**r file contains not only AIRS data but also AMSU-A, which is collocated with AIRS pixels (1 AMSU-A pixels collocated with 9 AIRS pixels). Users also have to place these files in the working directory where WRF-Var executable is located. Should be mentioned that WRF-Var reads directly these BUFR radiance files and no pre-processing is needed before WRF-Var assimilates them. All processing of radiance data, such as quality control, thinning and bias correction and so on, is carried out inside WRF-Var. This is different from conventional observation assimilation, which requires a pre-processing package (OBSPROC) to generate WRF-Var readable ASCII files. For reading radiance BUFR files, WRF-Var must be compiled with NCEP BUFR library (see <http://www.nco.ncep.noaa.gov/sib/decoders/BUFRLIB/>).

Table 1: NCEP and WRF-Var radiance BUFR file name convention

<i>NCEP BUFR file names</i>	<i>WRF-Var naming convention</i>
<i>gdas1.t00z.1bamua.tm00.bufr_d</i>	<i>amsua.bufr</i>
<i>gdas1.t00z.1bamub.tm00.bufr_d</i>	<i>amsub.bufr</i>
<i>gdas1.t00z.1bhrs3.tm00.bufr_d</i>	<i>hirs3.bufr</i>
<i>gdas1.t00z.1bhrs4.tm00.bufr_d</i>	<i>hirs4.bufr</i>
<i>gdas1.t00z.1bmhs.tm00.bufr_d</i>	<i>mhs.bufr</i>
<i>gdas1.t00z.airsev.tm00.bufr_d</i>	<i>airs.bufr</i>

A few namelist parameters are used to control if reading in corresponding BUFR files into WRF-Var or not. For instance, **USE_AMSUAOBS**, **USE_AMSUBOBS**, **USE_HIRS3OBS**, **USE_HIRS4OBS**, **USE_MHSOBS**, **USE_AIRSOBS**, **USE_EOS_AMSUAOBS** and **USE_SSMISOBS** control respectively to read the corresponding files or not. These are logical parameters and are assigned to FALSE by default (means that you must switch them to TRUE for reading in these data). Notice also that these parameters only control whether read in the data or not, but not control whether assimilate the data included in the files, which is controlled by other namelist parameters explained in the next section.

NCEP BUFR files are in the big endian format and can be directly used in IBM_{like} machines. For most Linux cluster with Intel platform, users need to convert them to little endian format. Some endian conversion tool exists (e.g., http://www.math.ucdavis.edu/~cheung/PROJECTS/DAO_Projects/halem/iret/reblock.c). The page <http://www.nco.ncep.noaa.gov/sib/decoders/BUFRLIB/toc/cwordsh> explains the issue of endianism in BUFR files with more details.

Radiative Transfer Model

The core component for direct radiance assimilation is to incorporate radiative transfer model (RTM, should be accurate enough yet fast) into WRF-Var system as one part of observation operators. Two widely used RTMs in NWP community, RTTOV8 developed by EUMETSAT in Europe and CRTM developed by the Joint Center for Satellite Data Assimilation (JCSDA) in US, are already implemented in WRF-Var system with flexible and consistent user interface. Using which RTM is controlled by a simple namelist parameter **RTM_OPTION** (1 for RTTOV by default, 2 for CRTM). WRF-Var is designed to be able to compile with only one of two RTM libraries or without RTM libraries (for those not interested in radiance assimilation) by simple setup of environment variables “CRTM” and “RTTOV” (see WRF-Var compilation guide).

Both RTMs can calculate radiances for almost all available instruments aboard various satellite platforms in orbit. An important feature of WRF-Var design is that all data structures related to radiance assimilation are dynamically allocated during running time according to simple namelist setup. The instruments to be assimilated are controlled by 4

integer namelist parameters in running time: **RTMINIT_NSENSOR** (total number of sensors to be assimilated), **RTMINIT_PLATFORM** (platforms IDs array to be assimilated with dimension RTMINIT_NSENSOR, e.g., 1 for NOAA, 9 for EOS, 10 for METOP and 2 for DMSP), **RTMINIT_SATID** (satellite IDs array) and **RTMINIT_SENSOR** (sensor IDs array, e.g., 0 for HIRS, 3 for AMSU-A, 4 for AMSU-B, 15 for MHS, 10 for SSMIS, 11 for AIRS). For instance, configuration for assimilating 12 sensors from 7 satellites (what WRF-Var can assimilated currently) will be

```
RTMINIT_NSENSOR = 12 # 5 AMSUA; 3 AMSUB; 2 MHS; 1 AIRS; 1 SSMIS
RTMINIT_PLATFORM = 1,1,1,9,10, 1,1,1, 1,10, 9, 2
RTMINIT_SATID = 15,16,18,2,2, 15,16,17, 18,2, 2, 16
RTMINIT_SENSOR = 3,3,3,3,3, 4,4,4, 15,15, 11, 10
```

The instrument triplets (platform, satellite and sensor ID) in the namelist can be rank in any order. More detail about the convention of instrument triplet can be found at the pages 4 and 5 in RTTOV8 Users Guide (http://www.metoffice.gov.uk/research/interproj/nwpsaf/rtn/rttov8_ug.pdf). It is also copied below for quick reference.

Platform	RTTOV id	Sat id range
NOAA [†]	1	1 to 18
DMSP	2	8 to 16
Meteosat	3	5 to 7
GOES	4	8 to 12
GMS	5	5
FY-2	6	2 to 3
TRMM	7	1
ERS	8	1 to 2
EOS	9	1 to 2
<i>METOP</i>	<i>10</i>	<i>1 to 3</i>
ENVISAT	11	1
MSG	12	1 to 2
FY-1	13	3
ADEOS	14	1 to 2
MTSAT	15	1
CORIOLIS	16	1

[†] Includes TIROS-N

Table 2. Platforms supported by RTTOV_8_7 as at 17 Nov 2005 in normal text. Platforms in italics are not yet supported by RTTOV_8_7 but soon will be.

Sensor	RTTOV Id	Sensor Channel #	RTTOV-7 Channel #	RTTOV-8 Channel #
HIRS	0	1 to 19	1 to 19	1 to 19
MSU	1	1 to 4	1 to 4	1 to 4
SSU	2	1 to 3	1 to 3	1 to 3
AMSU-A	3	1 to 15	1 to 15	1 to 15
AMSU-B	4	1 to 5	1 to 5	1 to 5
AVHRR	5	3b to 5	1 to 3	1 to 3
SSMI	6	1 to 7	1 to 7	1 to 4
VTPR1	7	1 to 8	1 to 8	1 to 8
VTPR2	8	1 to 8	1 to 8	1 to 8
TMI	9	1 to 9	1 to 5	1 to 9
SSMIS	10	1 to 24*	1 to 24*	1 to 21
AIRS	11	1 to 2378	1 to 2378	1 to 2378
HSB	12	1 to 4	1 to 4	1 to 4
MODIS	13	1 to 17	1 to 17	1 to 17
ATSR	14	1 to 3	1 to 3	1 to 3
MHS	15	1 to 5	1 to 5	1 to 5
<i>IASI</i>	16	1 to 8461	N/A	1 to 8461
AMSR	17	1 to 14	1 to 14	1 to 7
MVIRI	20	1 to 2	1 to 2	1 to 2
SEVIRI	21	4 to 11	1 to 8	1 to 8
GOES-Imager	22	1 to 4	1 to 4	1 to 4
GOES-Sounder	23	1 to 18	1 to 18	1 to 18
GMS/MTSAT imager	24	1 to 4	1 to 4	1 to 4
FY2-VISSR	25	1 to 2	1 to 2	1 to 2
FY1-MVISR	26	1 to 3	1 to 3	1 to 3
<i>CrIS</i>	27	TBD	N/A	TBD
<i>CMISS</i>	28	TBD	N/A	TBD
<i>VIIRS</i>	29	TBD	N/A	TBD
WINDSAT	30	1 to 10	N/A	1 to 5

*channels 19-21 are not simulated accurately

Table 3. Instruments supported by RTTOV_8_7 as at 17 Nov 2005.
Sensors in italics are not yet supported by RTTOV_8_7 but soon will

CRTM uses different instrument naming method. A convert routine inside WRF-Var is already created to make CRTM use the same instrument triplet as RTTOV such that the user interface remains the same for RTTOV and CRTM.

During WRF-Var running with radiance assimilation switched on (RTTOV or CRTM), a set of RTM coefficient files need to be loaded. For RTTOV option, RTTOV coefficient files are to be directly copied or linked under the working directory; for CRTM option, CRTM coefficient files are to be copied or linked to a sub-directory “crtm_coefs” under the working directory. Only coefficients listed in namelist are needed. Potentially WRF-Var can assimilate all sensors listed in the Table 3 as long as the corresponding coefficient files are provided with RTTOV and CRTM. In addition, necessary

developments on corresponding data interface, quality control and bias correction are also important to make radiance data assimilated properly. However, a modularized design of radiance relevant routines already facilitates much to add more instruments in WRF-Var.

RTTOV and CRTM packages are not distributed with WRF-Var due to license and support issues. Users are encouraged to contact the corresponding team for obtaining RTMs. Following links are a start point of contact:

<http://www.metoffice.gov.uk/research/interproj/nwpsaf/rtm/index.html> for RTTOV,
<http://www.jcsda.noaa.gov/> for CRTM.

Other Namelist variables to control radiance assimilation

RAD_MONITORING (30)

Integer array with dimension RTMINIT_NSENER, where 0 for assimilating mode, 1 for monitoring mode (only calculate innovation).

THINNING

Logical, TRUE will perform thinning

THINNING_MESH (30)

Real array with dimension RTMINIT_NSENSOR, values indicate thinning mesh (in KM) for different sensors.

READ_BIASCOEF

Logical, control if reading bias correction coefficient files (Harris and Kelly scheme), always set to TRUE.

BIASCORR

Logical, control if perform bias correction

BIASPREP

Logical, control if perform bias correction preparation. Will explain in next section.

QC_RAD

Logical, control if perform quality control, always set to TRUE.

WRITE_IV_RAD_ASCII

Logical, control if output Observation minus Background files, which are ASCII format and separated by sensor and processor.

WRITE_OA_RAD_ASCII

Logical, control if output Observation minus Analysis files (including also O minus

B), which are ASCII format and separated by sensor and processor.

USE_ERROR_FACTOR_RAD

Logical, control if use a radiance error tuning factor file “radiance_error.factor”, which is created with empirical values or generated using variational tuning method (Desroziers and Ivanov, 1997)

ONLY_SEA_RAD

Logical, control if only assimilating radiance over water.

TIME_WINDOW_MIN

String, e.g., "2007-08-15_03:00:00.0000", start time of assimilation time window

TIME_WINDOW_MAX

String, e.g., "2007-08-15_09:00:00.0000", end time of assimilation time window

Channel Selection

Channel selection in WRF-Var is controlled by some radiance ‘info’ files located in the sub-directory ‘radiance_info’ under the working directory. These files are separated by satellites and sensors, e.g., noaa-15-amsua.info, noaa-16-amsub.info, dmsp-16-ssmis.info and so on. An example for 5 channels from noaa-15-amsub.info is shown below. The fourth column is used by WRF-Var to control if assimilating corresponding channel. Channels with the value “-1” indicates “not assimilated” (channels 1, 2 and 4 in this case), with the value “1” means “assimilated” (channels 3 and 5). Other columns are not used by WRF-Var. In the future, we plan to incorporate the channel selection information in “info” files into “bias correction” files to simplify user’s configuration.

```
sensor channel IR/MW use idum  varch  polarisation(0:vertical;1:horizontal)
415  1  1  -1  0  0.5500000000E+01  0.0000000000E+00
415  2  1  -1  0  0.3750000000E+01  0.0000000000E+00
415  3  1  1  0  0.3500000000E+01  0.0000000000E+00
415  4  1  -1  0  0.3200000000E+01  0.0000000000E+00
415  5  1  1  0  0.2500000000E+01  0.0000000000E+00
```

Off-line bias correction statistics (Harris and Kelly Scheme)

Satellite radiance is generally considered biased with respect to a reference (e.g., background or analysis field in NWP assimilation) due to system error of observation itself, reference field and RTM. Bias correction is a necessary step prior to assimilating

radiance data. In WRF-Var, bias correction is carried out using a set of coefficient files pre-calculated with an off-line statistics package, which will apply to a training dataset for a month-long period. There are two steps for generating bias correction coefficient files.

Step 1: generate 'biasprep' files by running WRF-Var

This step is to generate “biasprep” files separated by sensor and processor, which contains necessary information (obs, background, o minus b, predictors etc.) for used by the off-line statistics. For statistical significance, month-long training dataset is preferred. Running WRF-Var with radiance data to be used and appropriate background field (e.g., produced from GFS analysis using WPS/REAL, or from a WRF 6h forecast in an existing assimilation experiment). Mention that the effect of bias correction can depend to some extent upon the reference field used for statistics. A sample namelist configuration for “biasprep” run of WRF-Var is listed below.

```
USE_AMSUAOBS=true
RTM_OPTION=2 # 1:rttov; 2:crtm
RTMINIT_NSENSOR=3
RTMINIT_PLATFORM=1,1,1
RTMINIT_SATID=15,16,18
RTMINIT_SENSOR=3,3,3
QC_RAD=true
READ_BIASCOEF=false
BIASCORR=false
BIASPREP=true # control to generate biasprep_* files
NTMAX=0 # no minimization needed
```

Note that “biasprep” run just need to calculate innovation, no minimization needed. NTMAX can be set to zero and it will be a cheap WRF-Var run. This configuration will generate a set of files, named “biasprep_noaa-15-amsua.*”, “biasprep_noaa-16-amsua.*”, “biasprep_noaa-18-amsua.*” (separated with processors) under the working directory. These files will be used for the off-line statistics described in the step 2.

Step 2: off-line statistics

Source codes for bias correction off-line statistics are located in ~wrfvar/da/da_biascorr_airmass, using './compile_all_wrfvar', or './compile_da_utils' to get executables in ~wrfvar/build directory, including da_bias_sele.exe, da_bias_scan.exe, da_bias_airmass.exe, da_bias_verif.exe.

A sample script ~wrfvar/scripts/da_bias_stat.ksh is already provided for a start point to generate bias correction coefficients for your own experiment. Important parameter setup in the script is summarized below:


```

export USER=liuz # your log on name
export WRFVAR_DIR=/ptmp/$USER/WRFVAR # your wrf-var directory
export DATA_DIR=/ptmp/$USER/t46/run
# assume biasprep* file is under ~run/yyyymmddhh/wrfvar/working
export BUILD_DIR=$WRFVAR_DIR/build # wrf-var executables
export WORKDIR=/ptmp/$USER/biasstat # BC statistics working directory
export START_DATE=2007070100 # start date of training dataset
export END_DATE=2007073118 # end date of training dataset
export CYCLE_PERIOD=6 # frequency in hour of training dataset
export PLATFORM=noaa # platform name; e.g., noaa, eos, dmsp, metop
export PLATFORM_ID=1 # platform ID, RTTOV name convention
export SENSOR=amsua # sensor name: amsua,amsub,ssmis, airs,mhs etc.
export SATELLITE=15 # satellite number: e.g., 15,16,17,18
export SENSOR_ID=3 # sensor ID, RTTOV convention, 3 for amsua; 4 for amsub etc.
export NSCAN=30 # number of scan angles, 30 for amsua, 90 for amsub/airs

```

Other useful information related to the namelist variables for da_bias_sele.exe, da_bias_scan.exe, da_bias_airmass.exe and da_bias_verif.exe can be found in the script.

Input of script is biasprep_\$PLATFORM-\$SATELLITE-\$SENSOR.* files generated from WRF-Var run described in the step 1.

Output of script is \$PLATFORM-\$SATELLITE-\$SENSOR.bcor , which is to be used for radiance assimilation.

Note that executing the script once can only get the coefficient file for one instrument, users needs to run the script for multi-times with specified instruments to obtain all sensors' coefficient you want for your experiment. The content of a sample coefficient file (ASCII format) for noaa-15-amsua.bcor is copied below (with comments).

```

15 30 18 4 # file header: 15 channels, 30 scan positions, 4 predictors
1 93735 214.92 18.03 -0.38 2.66 # first part for error standard deviation
2 78096 180.92 13.29 -0.48 3.12 # the last column is used as error bar of
3 100858 244.03 13.03 -0.29 2.04 # corresponding channel in WRF-Var.
4 103967 264.36 1.70 -0.05 0.41 # other columns are just for information goal
5 106176 255.40 3.66 0.06 0.20 # not used by WRF-Var
6 107952 238.33 4.38 0.09 0.14
7 106672 225.66 3.58 -0.06 0.13
8 106757 216.06 2.53 0.02 0.16
9 107971 210.62 2.06 0.01 0.23
10 107386 217.04 1.98 0.05 0.32
11 0 0.00 0.00 0.00 0.00
12 108117 227.57 1.80 -0.07 1.00
13 106235 230.84 1.46 -0.04 1.57
14 0 0.00 0.00 0.00 0.00
15 99390 258.92 12.60 -0.21 2.44

```

1	-0.00052	-0.00171	0.17026	0.05628	-23.97622	# the second part of the file
2	-0.00604	0.00192	0.05137	0.06828	80.95077	# coefficients for
3	-0.00550	0.00163	-0.07949	0.06356	116.69292	# air-mass BC correction
4	-0.00124	0.00051	-0.02516	0.01215	26.87520	
5	-0.00007	0.00000	0.00338	0.00208	1.24559	
6	0.00025	-0.00021	0.00489	0.00061	-5.63196	
7	-0.00024	0.00014	0.00446	0.00143	0.91211	
8	-0.00030	0.00026	0.00676	-0.00022	-0.13091	
9	0.00078	-0.00034	0.01635	-0.00406	-19.35943	
10	0.00138	-0.00077	0.02210	-0.00534	-28.98009	
11	0.00000	0.00000	0.00000	0.00000	0.00000	
12	0.00137	-0.00214	-0.04860	0.02725	14.98173	
13	0.00268	-0.00372	0.00338	0.04856	-4.04251	
14	0.00000	0.00000	0.00000	0.00000	0.00000	
15	-0.00636	0.00243	-0.19230	0.06684	157.92193	

RELATIVE SCAN BIASES # third part is relative scan bias of domain averaged

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30		
1	-14.07	-13.51	-11.89	-9.31	-6.91	-4.67	-2.97	-1.68	-0.84	-0.39	-0.15	0.19	0.21		
0.26	0.12	-0.12	-0.26	-0.42	-0.37	-0.80	-1.32	-2.05	-3.03	-4.22	-5.75	-7.83	-10.53		
-12.87	-14.15	-13.11													
2	-8.78	-9.46	-10.36	-12.17	-12.03	-8.56	-5.74	-3.41	-1.93	-1.16	-0.49	-0.12	0.04		
0.08	0.09	-0.09	-0.28	-0.55	-0.57	-1.19	-1.69	-2.45	-3.75	-5.47	-7.72	-10.63	-12.96		
-11.60	-9.63	-8.88													
3	-13.41	-12.16	-10.30	-8.24	-6.25	-4.57	-3.17	-2.25	-1.60	-1.04	-0.67	-0.27	-0.26		
-0.07	-0.01	0.01	0.01	-0.17	-0.27	-0.57	-0.99	-1.56	-2.30	-3.21	-4.53	-6.36	-8.44		
-10.63	-12.55	-13.86													
4	-1.88	-2.02	-2.01	-1.89	-1.61	-1.34	-1.06	-0.78	-0.56	-0.33	-0.24	-0.13	-0.04		
0.01	-0.01	0.01	0.00	-0.08	-0.17	-0.30	-0.43	-0.63	-0.85	-1.14	-1.47	-1.78	-2.15		
2.48	-2.73	-2.75													
5	-0.56	-0.62	-0.71	-0.71	-0.64	-0.57	-0.50	-0.41	-0.29	-0.19	-0.11	-0.06	-0.02		
0.01	0.00	0.00	0.02	0.01	-0.02	-0.11	-0.18	-0.29	-0.37	-0.50	-0.63	-0.84	-1.06		
1.16	-1.39	-1.39													
6	0.69	0.55	0.49	0.37	0.29	0.23	0.23	0.21	0.20	0.18	0.16	0.12	0.09		
0.06	0.03	-0.03	-0.04	-0.06	-0.06	-0.07	-0.06	-0.09	-0.10	-0.15	-0.15	-0.18	-0.33		
-0.41	-0.49	-0.49													
7	0.74	0.69	0.66	0.62	0.53	0.47	0.43	0.37	0.34	0.26	0.18	0.13	0.10		
0.02	0.01	-0.01	-0.04	-0.06	-0.03	0.02	0.09	0.19	0.24	0.26	0.26	0.30	0.16		
0.02	-0.03	-0.04													
8	0.13	0.05	-0.03	-0.05	0.02	0.02	-0.01	-0.01	-0.01	-0.01	-0.02	-0.03	-0.01		
0.02	-0.02	0.02	0.03	0.01	0.00	0.00	0.01	-0.04	-0.05	-0.08	-0.15	-0.21	-0.30		
0.31	-0.32	-0.30													
9	0.35	0.34	0.31	0.15	0.12	0.15	0.15	0.25	0.10	0.23	0.08	0.01	0.19		
0.08	-0.05	0.05	-0.01	-0.01	-0.18	0.00	-0.04	-0.12	-0.20	-0.15	-0.18	-0.16	-0.20		
0.27	-0.26	-0.19													

```

10 1.18 1.12 1.01 0.87 0.71 0.58 0.45 0.36 0.28 0.21 0.14 0.10 0.06
0.05 0.02 -0.02 -0.03 -0.04 -0.06 -0.05 -0.01 0.04 0.10 0.19 0.27 0.36 0.40
0.48 0.59 0.74
11 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00
12 0.27 -0.01 -0.24 -0.38 -0.43 -0.43 -0.42 -0.39 -0.31 -0.22 -0.17 -0.09 -0.03
0.01 0.02 -0.02 -0.06 -0.10 -0.20 -0.28 -0.36 -0.45 -0.50 -0.50 -0.48 -0.46
-0.33 -0.12 0.13
13 3.42 2.91 2.37 1.92 1.52 1.17 0.87 0.65 0.44 0.31 0.18 0.09 0.07
0.04 0.02 -0.02 -0.02 0.01 0.06 0.12 0.27 0.42 0.62 0.92 1.27 1.66 2.06
2.50 2.96 3.44
14 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00
15 -11.99 -10.93 -9.57 -7.93 -6.29 -4.75 -3.42 -2.27 -1.55 -0.99 -0.56 -0.25 -0.17
-0.02 -0.01 0.01 -0.01 -0.14 -0.28 -0.61 -0.88 -1.37 -2.03 -2.94 -4.10 -5.69 -7.35
-9.11 -10.51 -11.49

```

Once users generate BC coefficient files and place them in the right directory (~working/biascorr), WRF-Var can assimilate radiance data with the following namelist configurations for this case with 3 AMSU-A sensors:

```

USE_AMSUAOBS=true
RTM_OPTION=2 # use crtm
RTMINIT_NSENSOR=3 # 3 sensors
RTMINIT_PLATFORM=1,1,1 # NOAA
RTMINIT_SATID=15,16,18 # NOAA-15/16/18
RTMINIT_SENSOR=3,3,3 # AMSU-A
QC_RAD=true # Quality control (must be true)
ONLY_SEA_RAD=true # assimilate radiance only over sea
READ_BIASCOEF=true # read in BC coefficient files
BIASCORR=true # apply bias correction
WRITE_IV_RAD_ASCII=true # write ASCII OMB file output
WRITE_OA_RAD_ASCII=true # write ASCII OMB+OMA file output
THINNING=true
THINNING_MESH=120.0,120.0,120.0

```

Variational Bias Correction

Getting started with VarBC

Here a description of what you need to set to start VarBC experiments.

You need to activate the following namelist switch in record wrfvar14 in namelist.input:
USE_VARBC=true

In record wrfvar14, you also need to indicate the path for your ASCII file setting up
VarBC: DA_VARBC_IN=\${my_directory}/\${my_VarBC_file}

Finally, you need to have a VarBC setup file. Either you got one from a friendly colleague... Or you can create one from VARBC.in file.

VARBC.in file

This is the ASCII file that controls all of what is going into the VarBC. You can easily tune it to your own needs. Here is an example of VARBC.in file to perform VarBC for NOAA-15 AMSU-A and NOAA-16 AMSU-B:

```
VARBC version 1.0 - Number of instruments:
2
-----
Platform_id Sat_id Sensor_id Nchanl Npredmax
-----
1 15 3 5 8
----> Bias predictor statistics: Mean & Std & Nbgerr
  1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
  0.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0
  0      0      0      0      0      0      0      0
----> Chanl_id Chanl_nb Pred_use(-1/0/1) Param
  5  5 0 0 0 0 0 0 0 0
  6  6 0 0 0 0 0 0 0 0
  7  7 0 0 0 0 0 0 0 0
  8  8 0 0 0 0 0 0 0 0
  9  9 0 0 0 0 0 0 0 0
-----
Platform_id Sat_id Sensor_id Nchanl Npredmax
-----
1 16 4 3 8
----> Bias predictor statistics: Mean & Std & Nbgerr
  1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
  0.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0
```

```

      0   0   0   0   0   0   0   0
----> Chanl_id Chanl_nb Pred_use(-1/0/1) Param
3   3 0 0 0 0 0 0 0 0
4   4 0 0 0 0 0 0 0 0
5   5 0 0 0 0 0 0 0 0

```

Now here it comes with commentaries:

VARBC version 1.0 - Number of instruments:

2

This is number of instruments you want to bias correct with the VarBC. WRF-Var will loop through the VARBC.in file to read each instrument VarBC setup.

```

-----
Platform_id Sat_id Sensor_id Nchanl Npredmax
-----

```

1 15 3 5 8

This is the description for each instrument, including the defining triplet (platform, satellite ID, sensor), the number of channels (WRF-Var will loop through the VARBC.in file to read each channel), the maximum number of predictors. Here we have set NOAA-15 (1, 15) AMSU-A (3) for 5 channels (5) and 8 potential bias predictors (8).

----> Bias predictor statistics: Mean & Std & Nbgerr

```

1.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
0.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0
0     0     0     0     0     0     0     0

```

These lines define the bias predictor statistics. The first line corresponds to the predictor mean, the second line to the standard deviation. If you build your VARBC.in file from scratch, these lines do not matter (you still need to put dummy values in). The third line corresponds to the background constraint. You can easily start with zero for all predictors, which corresponds to "no background constraint".

----> Chanl_id Chanl_nb Pred_use(-1/0/1) Param

```

5   5 0 0 0 0 0 0 0 0
6   6 0 0 0 0 0 0 0 0
7   7 0 0 0 0 0 0 0 0
8   8 0 0 0 0 0 0 0 0
9   9 0 0 0 0 0 0 0 0

```

For each channel you want to bias correct with VarBC, set the channel index, channel number (different from the index for AIRS), and an integer flag for each predictor. The flag can be:

- -1: do not use this predictor

- 0: use this predictor and start the corresponding parameter from scratch (= "Coldstart")
- 1: use this predictor and read the value of the corresponding parameter at the end the line

Here we have just coldstarted every predictor for each of the five channels for NOAA-15 AMSU-A. Now we can follow the same procedure for NOAA-16 AMSU-B.

```
-----
Platform_id Sat_id Sensor_id Nchanl Npredmax
-----
1 16 4 3 8
----> Bias predictor statistics: Mean & Std & Nbgerr
  1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
  0.0    1.0    1.0    1.0    1.0    1.0    1.0    1.0
  0      0      0      0      0      0      0      0
----> Chanl_id Chanl_nb Pred_use(-1/0/1) Param
3   3 0 0 0 0 0 0 0 0
4   4 0 0 0 0 0 0 0 0
5   5 0 0 0 0 0 0 0 0
```

Input and Output files

All VarBC input is passed through one single ASCII file called VARBC.in file. Once WRF-Var has run with the VarBC option switched on, it will produce a VARBC.out file which looks very much like the VARBC.in file you provided. This output file will then be used as input file for the next assimilation cycle.

Coldstart

Coldstarting = starting the VarBC from scratch... i.e. when you do not know the values of the bias parameters.

The Coldstart is a routine in WRF-Var. The bias predictor statistics (mean and standard deviation) are computed automatically and will be used to normalize the bias parameters. All coldstarted bias parameters are set to zero, except the first bias parameter (= simple offset), which is set to the mode (=peak) of the distribution of the (uncorrected) innovations for the given channel.

Currently a threshold of 100 observations is hard-coded, under which it is considered that not enough observations are present to keep the Coldstart values (i.e. bias predictor statistics and bias parameter values) for the next cycle. In this case, the next cycle will do an other Coldstart.

Background Constraint for the bias parameters

The background Constraint controls the inertia you want to impose on the predictors (i.e. the smoothing in the predictor timeseries). It corresponds to an extra term in the WRF-Var cost function.

It is defined through an integer number in the VARBC.in file. This number is related to a number of observations: the bigger the number, the more inertia constraint. If these numbers are set to zero, the predictors can evolve without any constraint.

Scaling factor

The VarBC uses a specific preconditioning, which can be scaled through a namelist parameter in record wrfvar14 in namelist.input. By default, VARBC_FACTOR=1.0

Offline bias correction

The analysis of the VarBC parameters can be performed "offline", i.e. independently from the main WRF-Var analysis. No extra code is needed, you just set the following values for the namelist variables in record wrfvar13 in namelist.input, which will disable the standard control variable and only keep the VarBC control variable.

```
MAX_VERT_VAR1=0.0  
MAX_VERT_VAR2=0.0  
MAX_VERT_VAR3=0.0  
MAX_VERT_VAR4=0.0  
MAX_VERT_VAR5=0.0
```

Freeze VarBC

In certain circumstances, you might want to keep the VarBC bias parameters constant in time ("frozen"). In this case, the bias correction is read and applied to the innovations, but it is not updated during the minimization. This can easily be achieved by setting in record wrfvar14 in namelist.input:

```
USE_VARBC=false  
FREEZE_VARBC=true
```

Passive observations

Some observations are useful for preprocessing (e.g. Quality Control, Cloud detection) but you might not want to assimilate them. If you still need to estimate their bias correction, these observations need to go through the VarBC code in the minimization. For this purpose, the VarBC uses a separate threshold on the QC values, called "qc_varbc_bad". This threshold is currently set to the same value as "qc_bad", but can easily be changed to any ad hoc value.

Diagnostics and Monitoring

(1) Monitoring capability within WRF-Var.

Run WRF-Var with the `rad_monitoring` namelist parameter in record `wrfvar14` in `namelist.input`.

0 means assimilating mode, innovations (O minus B) are calculated and data are used in minimization.

1 means monitoring mode: innovations are calculated for diagnostics and monitoring. Data are not used in minimization.

Numbers of `rad_monitoring` should correspond to number of `rtminit_nsensor`. If `rad_monitoring` is not set, then default value of 0 will be used for all sensors.

(2) Outputting radiance diagnostics from WRF-Var

Run WRF-Var with the following namelist variables in record `wrfvar14` in `namelist.input`.

`write_iv_rad_ascii=.true.`

to write out (observation-background) and other diagnostics information in plain-text files with prefix `inv` followed by instrument name and processor id. For example, `inv_noaa-17-amsub.00`

`write_oa_rad_ascii=.true.`

to write out (observation-background), (observation-analysis) and other diagnostics information in plain-text files with prefix `oma` followed by instrument name and processor id. For example, `oma_noaa-18-mhs.01`

Each processor writes out information of one instrument in one file in the WRF-var working directory.

(3) Radiance diagnostics data processing

A Fortran90 program is used to collect the `inv*` or `oma*` files and write out in netCDF format (one instrument in one file with prefix `diags` followed by instrument name, analysis date, and suffix `.nc`) for easier data viewing, handling and plotting with netCDF utilities and NCL scripts.

(4) Radiance diagnostics plotting

NCL scripts are used for plotting. The NCL script can be run from a shell script (a sample shell script is located in `~wrfvar/scripts/da_rad_diags.ksh`), or run stand-alone with interactive `ncl` command (need to edit the NCL script and set the plot options).

Also the path of `advance_cymdh.ncl`, a date advancing script loaded in the main NCL plotting script, may need to be modified).

Step (3) and (4) can be done by running a single ksh with proper settings. In addition to the settings of directories and what instruments to plot, there are some useful plotting options, explained below.

<code>export OUT_TYPE=ncgm</code>	<i>ncgm or pdf pdf will be much slower than ncgm and generate huge output if plots are not splitted. But pdf has higher resolution than ncgm.</i>
<code>export PLOT_STATS_ONLY=false</code>	<i>true or false true: only statistics of OMB/OMA vs channels and OMB/OMA vs dates will be plotted. false: data coverage, scatter plots (before and after bias correction), histograms (before and after bias correction), and statistics will be plotted.</i>
<code>export PLOT_OPT=sea_only</code> <code>export PLOT_QCED=false</code>	<i>all, sea_only, land_only true or false true: plot only quality-controlled data false: plot all data</i>
<code>export PLOT_SPLIT=false</code>	<i>true or false true: one frame in each file false: all frames in one file</i>
<code>export PLOT_CLOUDY=false</code>	<i>true or false true: plot cloudy data. Cloudy data to be plotted are defined by PLOT_CLOUDY_OPT (si or clwp), CLWP_VALUE, SI_VALUE settings.</i>
<code>export PLOT_CLOUDY_OPT=si</code>	<i>si or clwp clwp: cloud liquid water path from model si: scatter index from obs, for amsua, amsub and mhs only</i>
<code>export CLWP_VALUE=0.2</code>	<i>only plot points with clwp >= clwp_value (when clwp_value > 0) clwp > clwp_value (when clwp_value = 0)</i>
<code>export SI_VALUE=3.0</code>	

Description of Namelist variables (variables with red color are mostly possible used)

<i>Variable Names</i>	<i>Default Value in Registry</i>	<i>Description</i>
<i>&WRFVAR4</i>		
<i>USE_HIRS2OBS</i>	<i>FALSE</i>	
<i>USE_HIRS3OBS</i>	<i>FALSE</i>	
<i>USE_HIRS4OBS</i>	<i>FALSE</i>	
<i>USE_MHSOB</i>	<i>FALSE</i>	
<i>USE_MSUOBS</i>	<i>FALSE</i>	
<i>USE_AMSUAOBS</i>	<i>FALSE</i>	
<i>USE_AMSUBOBS</i>	<i>FALSE</i>	
<i>USE_AIRSOBS</i>	<i>FALSE</i>	
<i>USE_EOS_AMSUAOBS</i>	<i>FALSE</i>	
<i>USE_EOS_RADOBS</i>	<i>FALSE</i>	
<i>USE_HSB_OBS</i>	<i>FALSE</i>	
<i>USE_SSMISOBS</i>	<i>FALSE</i>	
<i>USE_FILTERED_RAD</i>	<i>FALSE</i>	
<i>&WRFVAR14</i>		
<i>RTMINIT_PRINT</i>	<i>1</i>	<i>For RTTOV only 0 = no error messages output 1 = FATAL errors only printed. 2 = WARNING errors only printed. 3 = INFORMATION messages Any other value is treated as 3</i>
<i>RTMINIT_NSENSOR</i>	<i>1</i>	
<i>RTMINIT_PLATFORM (30)</i>	<i>-1</i>	
<i>RTMINIT_SATID (30)</i>	<i>-1</i>	
<i>RTMINIT_SENSOR (30)</i>	<i>-1</i>	
<i>RAD_MONITORING (30)</i>	<i>0</i>	<i>0: assimilating</i>

1: monitoring

<i>THINNING_MESH</i> (30)	60.0	
<i>THINNING</i>	FALSE	
<i>READ_BIASCOEF</i>	TRUE	
<i>BIASCORR</i>	FALSE	
<i>BIASPREP</i>	FALSE	
<i>RTTOV_SCATT</i>	FALSE	
<i>WRITE_PROFILE</i>	FALSE	
<i>WRITE_JACOBIAN</i>	FALSE	
<i>QC_RAD</i>	TRUE	
<i>WRITE_IV_RAD_ASCII</i>	FALSE	
<i>WRITE_OA_RAD_ASCII</i>	FALSE	
<i>WRITE_FILTERED_RAD</i>	FALSE	
<i>USE_ERROR_FACTOR_RAD</i>	FALSE	
<i>USE_LANDEM</i>	FALSE	
<i>MW_EMIS_SEA</i>	1	
<i>TOVS_MIN_TRANSFER</i>	10	
<i>TOVS_BATCH</i>	FALSE	
<i>RTM_OPTION</i>	1	1: RTTOV 2: CRTM
<i>USE_CRTM_KMATRIX</i>	FALSE	
<i>USE_CRTM_KMATRIX_FAST</i>	FALSE	
<i>CRTM_CLOUD</i>	FALSE	
<i>ONLY_SEA_RAD</i>	FALSE	
<i>USE_SIMULATED_RAD</i>	FALSE	
<i>USE_PSEUDO_RAD</i>	FALSE	
<i>PSEUDO_RAD_PLATID</i>	1	
<i>PSEUDO_RAD_SATID</i>	16	
<i>PSEUDO_RAD_SENID</i>	3	
<i>PSEUDO_RAD_ICHAN</i>	6	
<i>PSEUDO_RAD_LAT</i>	35.0	
<i>PSEUDO_RAD_LON</i>	130.0	
<i>PSEUDO_RAD_TB</i>	258.0	
<i>PSEUDO_RAD_ERR</i>	1.0	
<i>SPCCOEFF_FILE</i>	<i>CRTM_SpcCoeff.bin</i>	
<i>TAUCOEFF_FILE</i>	<i>CRTM_TauCoeff.bin</i>	
<i>AEROSOLCOEFF_FILE</i>	<i>CRTM_AerosolCoeff.bin</i>	
<i>CLOUDCOEFF_FILE</i>	<i>CRTM_CldCoeff.bin</i>	
<i>EMISCOEFF_FILE</i>	<i>CRTM_EmisCoeff.bin</i>	
<i>USE_VARBC</i>	FALSE	
<i>FREEZE_VARBC</i>	FALSE	
<i>VARBC_FACTOR</i>	1.0	