Radiance Data Assimilation in WRFDA

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Outline

• An introduction of radiance data assimilation
  – Principal of satellite measurements
  – Introduction to the Radiative Transfer theory
  – Elements of Radiance DA

• Practical aspects with WRFDA
Part I: An Introduction of radiance data assimilation
Polar-orbiting satellites

Geostationary satellites

NOAA-15  NOAA-16  NOAA-17

Goes-W  Goes-E  Met-7  Met-5  GMS(Goes-9)
Cross-track scan geometry of satellite instruments
TMI/SSMI/SSMIS scan geometry

Conical scan

Same size of foot-print

Fig. 1. Schematic view of the scan geometries of the three TRMM primary rainfall sensors: TMI, PR, and VIRS.
What do satellite instruments measure?

They DO NOT measure TEMPERATURE
They DO NOT measure HUMIDITY
They DO NOT measure WIND

Satellite (passive) instruments simply measure the radiance (energy in specific unit) that reaches the top of the atmosphere (TOA) at frequency range $\nu_1 \sim \nu_2$. The measured radiance is related to geophysical atmospheric variables by the radiative transfer equation. Radiances are often converted to “brightness temperature” (equivalent blackbody temperature, by inverting Plank function).
Passive Sensors from Weather/Environment Satellites

Electromagnetic Spectrum
Why assimilating Radiances?

Avoid complicated errors (random and systematic) introduced by pre-processing such as cloud clearing, angle (limb) adjustment and surface corrections.

Avoid having to change (retune) data assimilation system when the data provider changes the pre-processing/retrieval.

Faster access to data from new platforms (e.g. AMSU data from NOAA-16 assimilated 6 weeks after launch).

Allows consistent treatment of historical data for re-analysis applications.
Radiative Transfer: Forward model

\[ L(\nu) = \int_0^\infty B(\nu, T(z)) \left[ \frac{d\tau(\nu)}{dz} \right] dz \]

- **TOA radiance at frequency \( \nu \)**
- **Planck function**
- **Atmospheric Absorption (weighting function)**
- **Surface**
- **Cloud/Rain Aerosol**
- **Emission/reflection**
- **Diffusion/scattering**

**Surface emission \( R_s \)**

**Up-welling atmosphere emission \( R_A \)**

**Reflected solar radiation \( R_O \)**

**Down-welling & reflected atmos. Emission (\( R_D \))**
Weighting functions of different channels

Window Channels 
(1~4,15) not used

Ch4: 700mb 
Ch5: 500~700mb 
Ch6: 400~500mb 
Ch7: 200~300mb

Sounding Channels 
(5~11) sensitive to Temperature.

Ch8: 200mb 
Ch9: 100mb 
Ch10: 50mb 
Ch11: 30mb

Channels above model top should not be used.

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Radiance Assimilation in 3D/4D-VAR

Solving the inverse problem by minimizing a cost function

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

Observation operators include Radiative Transfer Model

1. Solving the inverse problem along with other observations in a more consistent way.

2. Pixels are no longer independent each other due to the horizontal correlation in B.

3. Can affect no-measured quantities through multivariate correlation in B.
Radiance obs is biased

\begin{align*}
\text{noaa-18-amsua\_ch0007} & \quad 3116 \\
\text{mean:} & \quad -1.988 \\
\text{stdv:} & \quad 0.485 \\
\text{rms :} & \quad 2.047 \\
\end{align*}

\begin{align*}
\text{mean:} & \quad 0.038 \\
\text{stdv:} & \quad 0.454 \\
\text{rms :} & \quad 0.456 \\
\end{align*}
Variational Bias Correction (VarBC) in WRFDA (T. Auligné)

Modeling of errors in satellite radiances:

\[ y = H(x_t) + B(\beta) + \varepsilon \]

\[ \langle \varepsilon \rangle = 0 \]

\[ B(\beta) = \sum_{i=1}^{N} \beta_i \hat{p}_i \]

Bias parameters can be estimated within the variational assimilation, jointly with the atmospheric model state (Derber and Wu 1998) (Dee 2005) (Auligné et al. 2007)

Inclusion of the bias parameters in the control vector: \( x^T \rightarrow [x, \beta]^T \)

\[ J_b: \text{background term for} \ x \]

\[ J_p: \text{background term for} \ \beta \]

\[ J_o: \text{corrected observation term} \]

Can be used for radiance offline monitoring by removing \( J_b \) term and other obs., and using some analysis fields as reference.

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Radiance Monitoring against ERA-Interim over Arctic domain
Dense data are very likely correlated, which is not taken into account in the observation covariance matrix $R$. 

Observation Thinning

No Thinning

120km Thinning Mesh

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Part II: Practice with WRFDA

- Data Ingest \textit{(sources, instruments)}
- Radiative transfer model
- Channel selection
- Variational Bias correction
- Diagnostics and monitoring
• NCEP global BUFR format radiance data within a 6h time window (Total: 18 sensors from 7 satellites)
  – 5 HIRS from NOAA16, 17, 18, 19, METOP-2
  – 6 AMSU-A from NOAA15,16,18,19, EOS-Aqua, METOP-2
  – 3 AMSU-B from NOAA15, 16, 17
  – 3 MHS from NOAA18, 19, METOP-2
  – 1 AIRS from EOS-Aqua

• NRL/AFWA/NESDIS produced DMSP-16 SSMI/S BUFR radiance data.
NCEP near real-time ftp server with radiance BUFR data

NOAA Historical archive:  http://nomads.ncdc.noaa.gov/data/gdas/
NCAR archive: http://dss.ucar.edu/datasets/ds735.0/

NCEP naming convention
- gdas1.t00z.1bamua.tm00.bufr_d
- gdas1.t00z.1bamub.tm00.bufr_d
- gdas1.t00z.1bhrs3.tm00.bufr_d
- gdas1.t00z.1bhrs4.tm00.bufr_d
- gdas1.t00z.1bmhs.tm00.bufr_d
- gdas1.t00z.airsev.tm00.bufr_d

WRF-Var naming convention
- amsua.bufr
- amsub.bufr
- hirs3.bufr
- hirs4.bufr
- mhs.bufr
- airs.bufr

Direct input to WRFDA, no pre-processing required.
Quality control, thinning, time and domain check, bias correction are done inside WRF-Var

Namelist switches to decide if reading the data or not
- Use_amsuaobs
- Use_amsubobs
- Use_hirs3obs
- Use_hirs4obs
- Use_mhsobs
- Use_airsobs
- Use_eos_amsuaobs
- Use_ssmisobs
Choose Radiative Transfer Model

Controlled by the namelist variable: “rtm_option”

2=CRTM (Community Radiative Transfer Model)
JCSDA (Joint Center for Satellite Data Assimilation)
Latest released version: CRTM REL-2.0.5,
Version included in WRFDA: CRTM REL-2.0.2
CRTM code and (limited) coeffs included in WRFDA release (since V3.2.1)

1=RTTOV (Radiative Transfer for TOVS)
EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)
http://research.metoffice.gov.uk/research/interproj/nwpsaf/rtm
Latest released version: RTTOV10.2,
Version used in WRFDA: RTTOV10
Channel selection and error specification

```
WRFDA/var/run/radiance_info>ls -l
```

```
total 160
-rw-r--r-- 1 hclin users 1588 Aug 22 17:01 dmsp-16-ssmis.info
-rw-r--r-- 1 hclin users 17790 Aug 22 17:01 eos-2-airs.info
-rw-r--r-- 1 hclin users 1033 Aug 22 17:01 eos-2-amsua.info
-rw-r--r-- 1 hclin users 1036 Aug 22 17:01 metop-2-amsua.info
-rw-r--r-- 1 hclin users  391 Aug 22 17:01 metop-2-mhs.info
-rw-r--r-- 1 hclin users 1021 Aug 22 17:01 noaa-15-amsua.info
-rw-r--r-- 1 hclin users  391 Aug 22 17:01 noaa-15-amsub.info
-rw-r--r-- 1 hclin users 1277 Aug 22 17:01 noaa-15-hirs.info
-rw-r--r-- 1 hclin users 1021 Aug 22 17:01 noaa-16-amsua.info
-rw-r--r-- 1 hclin users  391 Aug 22 17:01 noaa-16-amsub.info
-rw-r--r-- 1 hclin users 1275 Aug 22 17:01 noaa-16-hirs.info
-rw-r--r-- 1 hclin users 1277 Aug 22 17:01 noaa-17-hirs.info
-rw-r--r-- 1 hclin users 1036 Aug 22 17:01 noaa-18-amsua.info
-rw-r--r-- 1 hclin users 1286 Aug 22 17:01 noaa-18-hirs.info
-rw-r--r-- 1 hclin users  391 Aug 22 17:01 noaa-18-mhs.info
```

**metop-2-mhs.info**

```
-1: not used; 1: used           error for each channel
```

<table>
<thead>
<tr>
<th>sensor channel</th>
<th>IR/MW use</th>
<th>idum</th>
<th>varch</th>
<th>polarisation(0:vertical;1:horizontal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>203</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>0 0.25000000000E+01 0.00000000000E+00</td>
</tr>
<tr>
<td>203</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>0 0.25000000000E+01 0.00000000000E+00</td>
</tr>
<tr>
<td>203</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0 0.25000000000E+01 0.10000000000E+01</td>
</tr>
<tr>
<td>203</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0 0.20000000000E+01 0.10000000000E+01</td>
</tr>
<tr>
<td>203</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0 0.20000000000E+01 0.00000000000E+00</td>
</tr>
</tbody>
</table>

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Setup and run WRFDA with radiances

To run WRFDA, first create a working directory, for example, WRFDA/var/test, then follow the steps below:

cd WRFDA/var/test (go to the working directory)

ln -sf WRFDA/run/LANDUSE.TBL ./LANDUSE.TBL
ln -sf $DAT_DIR/rc/2007010200/wrfinput_d01 ./fg (link first guess file as fg)
ln -sf WRFDA/var/obsproc/obs_gts_2007-01-02_00:00:00.3DVAR ./ob.ascii (link OBSPROC processed observation file as ob.ascii)
ln -sf $DAT_DIR/be/be.dat ./be.dat (link background error statistics as be.dat)
ln -sf WRFDA/var/da/da_wrfvar.exe ./da_wrfvar.exe (link executable)

ln -sf $DAT_DIR/2007010200/gdas1.t00z.1bamua.tm00.bufr_d ./amsua.bufr
ln -sf ~WRFDA/var/run/radiance_info ./radiance_info
ln -sf ~WRFDA/var/run/VARB C.in.

(CRTM only) > ln -sf WRFDA/var/run/crtm_coeffs ./crtm_coeffs #(crtm_coeffs is a directory)
(RTTOV only) > ln -sf your_path/rtcoef_rttov10/rttov7pred51L ./rttov_coeffs #(rttov_coeffs is a directory)

vi namelist.input (&wrfvar4, &wrfvar14, &wrfvar21, &wrfvar22)

    da_wrfvar.exe >&! wrfda.log
Control which instruments to be assimilated and Which CRTM/RTTOV coeffs files to be loaded

Namelist variables for tested instruments:

RTMINIT_NSENSOR  =  14
RTMINITPLATFORM  =  1, 1, 1, 1, 9, 10, 1, 1, 1, 1, 1, 10, 9, 2
RTMINIT_SATID    =  15, 16, 18, 19, 2, 2, 15, 16, 17, 18, 19, 2, 2, 16
RTMINIT_SENSOR   =  3, 3, 3, 3, 3, 3, 4, 4, 4, 4, 15, 15, 15, 11, 10

NOAA-15-AMSUA (1, 15, 3)
NOAA-16-AMSUA
NOAA-18-AMSUA
NOAA-19-AMSUA
EOS-2-AMSUA ( 9, 2, 3)
METOP-2-AMSUA (10, 2, 3)
NOAA-15-AMSUB (1, 15, 4)
NOAA-16-AMSUB
NOAA-17-AMSUB
NOAA-18-MHS (1, 18, 15)
NOAA-19-MHS
METOP-2-MHS (10, 2, 15)
EOS-2-AIRS ( 9, 2, 11)
DMSP-16-SSMIS ( 2, 16, 10)

CRTM and RTTOV share the same “instrument triplet” convention for user’s config.

This facilitates the user’s config. When switch b.w. two RTMs.
more sensors supported, from RTTOV_8_7 Users Guide

**Instrument triplets**
- platform_id
- satellite_id
- sensor_id

**Platform triplets**

<table>
<thead>
<tr>
<th>Platform</th>
<th>RTTOV id</th>
<th>Sat id range</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA</td>
<td>1</td>
<td>1 to 18</td>
</tr>
<tr>
<td>DMSP</td>
<td>2</td>
<td>8 to 16</td>
</tr>
<tr>
<td>Meleosat</td>
<td>3</td>
<td>5 to 7</td>
</tr>
<tr>
<td>GOES</td>
<td>4</td>
<td>8 to 12</td>
</tr>
<tr>
<td>GMS</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>FY-2</td>
<td>6</td>
<td>2 to 3</td>
</tr>
<tr>
<td>TRMM</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>ERS</td>
<td>8</td>
<td>1 to 2</td>
</tr>
<tr>
<td>EOS</td>
<td>9</td>
<td>1 to 2</td>
</tr>
<tr>
<td>METOP</td>
<td>10</td>
<td>1 to 3</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>MSG</td>
<td>12</td>
<td>1 to 2</td>
</tr>
<tr>
<td>FY-1</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>ADEOS</td>
<td>14</td>
<td>1 to 2</td>
</tr>
<tr>
<td>MTSAT</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>CORIOLIS</td>
<td>16</td>
<td>1</td>
</tr>
</tbody>
</table>

*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.

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

*Channels 19-21 are not simulated accurately.
Radiance namelist variables

**THINNING**: Logical, TRUE will perform thinning

**THINNING_MESH** (30): Real array with dimension RTMINIT_NSENSOR, values indicate thinning mesh (in KM) for different sensors.

**QC_RAD=true**: 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 sensors and processors.

**WRITE_OA_RAD_ASCII**: Logical, control if output Observation minus Analysis files (including also O minus B), which are ASCII format and separated by sensors and processors.

**ONLY_SEA_RAD**: Logical, control if only assimilating radiance over water.

**USE_CRTM_KMATRIX**: new from Version 3.1.1, much faster. Set to TRUE.

**USE_RTTOV_KMATRIX**: new from version 3.3, much faster. Set to TRUE
Radiance namelist (VarBC related)

`SE_VARBC=true`

`freeze_varbc=false` (VarBC coeffs not change during minimization)

`varbc_factor=1.` (for scaling the VarBC preconditioning)

`varbc_nbgeerr=5000`, (default value prior to V3.3.1 is 1 which is improper)

`varbc_nobsmin=500.` (defines the minimum number of observations required for the computation of the predictor statistics during the first assimilation cycle. If there are not enough data (according to "VARBC_NOBSMIN") on the first cycle, the next cycle will perform a coldstart again)
Variational Bias Correction (VarBC)

**VARBC.in** file is an ASCII file that controls all of what is going into the VarBC.

**Sample VARBC.in**

VARBC version 1.0 - Number of instruments: 2

Platform_id  Sat_id  Sensor_id  Nchanl  Npredmax

<table>
<thead>
<tr>
<th>Platform_id</th>
<th>Sat_id</th>
<th>Sensor_id</th>
<th>Nchanl</th>
<th>Npredmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std</th>
<th>Nbgerr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>10000</td>
<td>10000</td>
<td>10000</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Chanl_id</th>
<th>Chanl_nb</th>
<th>Pred_use</th>
<th>Param</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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Sample VARBC.out (output from WRF-Var, used as VARBC.in for the next cycle)

VARBC version 1.0 - Number of instruments:
4
Platform_id  Sat_id  Sensor_id  Nchanl  Npredmax
1 15 4 5 8

------> Bias predictor statistics:  Mean & Std & Nbgerr
1.0  9273.1   8677.8  290.4  24.0  51.7  3502.8  260484.8
0.0  273.5    293.3   8.0  12.3  28.9  2827.2  252657.9
10000 10000 10000 10000 10000 10000 10000 10000

------> Chanl_id Chanl_nb  Pred_use(-1/0/1)  Param
1  1  0  0  0  0  0  0  0  0  -3.400  0.000  0.000  0.000  0.000  0.000  0.000  0.000
2  2  0  0  0  0  0  0  0  0  -0.200  0.000  0.000  0.000  0.000  0.000  0.000  0.000
3  3  1  1  1  1  1  1  1  1  1.213  -0.062  0.003  -0.070  0.015  -0.059  0.304  0.241  0.203
4  4  1  1  1  1  1  1  1  1  3.056  0.050  0.053  0.015  -0.059  0.304  0.241  0.203
5  5  1  1  1  1  1  1  1  1  0.869  0.034  -0.089  0.074  0.019  -0.118  -0.031  0.022

Platform_id  Sat_id  Sensor_id  Nchanl  Npredmax
1 16 4 5 8

------> Bias predictor statistics:  Mean & Std & Nbgerr
1.0  9280.2   8641.2  290.0  24.1  52.6  3568.9  264767.4
0.0  209.5  245.9   7.9  11.3  28.3  2792.1  249977.0
10000 10000 10000 10000 10000 10000 10000 10000

------> Chanl_id Chanl_nb  Pred_use(-1/0/1)  Param
1  1  0  0  0  0  0  0  0  0   0.700  0.000  0.000  0.000  0.000  0.000  0.000  0.000
2  2  0  0  0  0  0  0  0  0  -0.800  0.000  0.000  0.000  0.000  0.000  0.000  0.000
3  3  1  1  1  1  1  1  1  1  0.372  -0.028  0.010  -0.060  0.025  0.117  0.023  -0.042
4  4  1  1  1  1  1  1  1  1  0.968  0.016  -0.003  -0.041  0.045  -0.018  -0.030  -0.028
5  5  1  1  1  1  1  1  1  1  -3.290  0.073  -0.093  0.096  0.018  0.011  0.010  0.004

Control whether a cold-start (if 0) Or warm-start (if 1) VarBC
Bias correction coefficients for 8 predictors (used only for warm-start case)

WRFDA Tutorial, July 2012
Radiance output Post-Processing/Visualization

• ~WRFDA/var/scripts/da_rad_diags.ksh (included in the TOOLS bundle that can be downloaded from http://www.mmm.ucar.edu/wrf/users/wrfda/download/tools.html

  – WRFDA will output radiance inv* or oma* ASCII files separated for different sensors and CPUs.
  – Script converts ASCII files to one NETCDF file for each sensor (a Fortran90 program), then plot *.nc files with a NCL script
  – NCL script can plot various graphics
    • Channel TB, Histogram, scatter plot, time series etc.
    • Can be included in the script to routinely produce graphics after WRF-Var runs
    • Users can control (by simple script parameter setup) to plot over smaller domain, only over land or sea, QCed or no-QCed observations.
Time series of radiance OMB/OMA for DMSP-16 SSMI/S
Conclusions

- **Radiance data assimilation are important**
  - Major source of information over ocean and Southern Hemisphere

- **Radiance DA is not trivial**
  - Very easy to degrade the analysis!
  - Each sensor requires a lot of attention (observation operator, bias correction, QC, observation error, cloud/rain detection, …)
  - Challenge for regional DA: lower model top, bias correction

- **It’s only the beginning…**
  - New generation of satellite instruments
  - Future developments will increase satellite impact
    - Better representation of surface emissivity over land
    - Use of cloudy/rainy radiances

- **Get familiar with radiance DA with more practice**
  - wrfhelp@ucar.edu