

Radiance Data Assimilation in WRFDA

**Zhiquan Liu (liuz@ucar.edu)
NCAR/MMM**

Work supported by AFWA, NASA, NSF, KMA



Outline

- An introduction of radiance data assimilation
 - Principal of satellite measurements
 - Introduction to the Radiative Transfer theory
 - Practical implementation
- Practical aspects with WRFDA



Part I: An Introduction of radiance data assimilation



Satellite Data Used or Tested at JCSDA and NCEP

~33 instruments are used

- HIRS sounder radiances
- AMSU-A sounder radiances
- AMSU-B/MHS sounder radiances
- GOES sounder radiances
- GOES, Meteosat, GMS winds
- GOES precipitation rate
- SSM/I precipitation rate
- TRMM precipitation rate
- SSM/I ocean surface wind speeds
- ERS-2 ocean surface wind vectors
- Quikscat ocean surface wind vectors
- AVHRR SST
- AVHRR vegetation fraction
- AVHRR surface type
- Multi-satellite snow cover
- Multi-satellite sea ice
- SBUV/2 ozone profile and total ozone
- Altimeter sea level observations (ocean data assimilation)
- AIRS
- MODIS Winds
- COSMIC

instruments are being tested

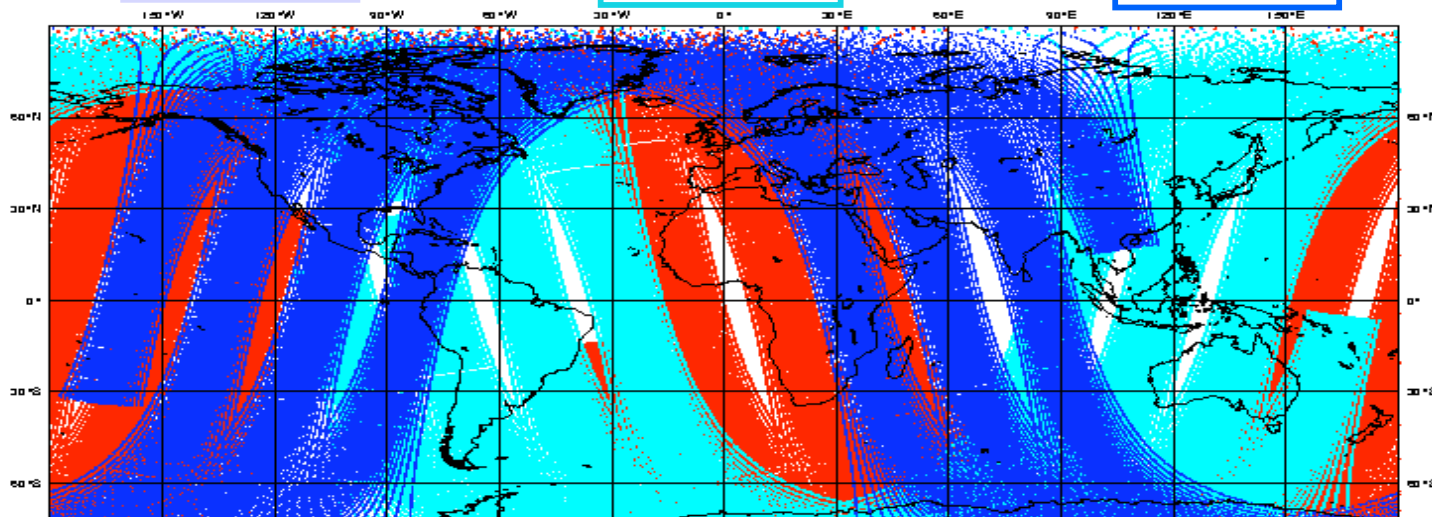
- *F16 SSMIS*
- *WindSat EDR, SDR assimilation*
- *OMI total ozone*
- *Cloudsat for CRTM validation*
- *Aura MLS*
- *IASI*
- *ASCAT*
- *GRAS*
- *GOME2*
- *FY-2*

**Not all assimilated in raw radiances,
Some also in retrieved quantities.**

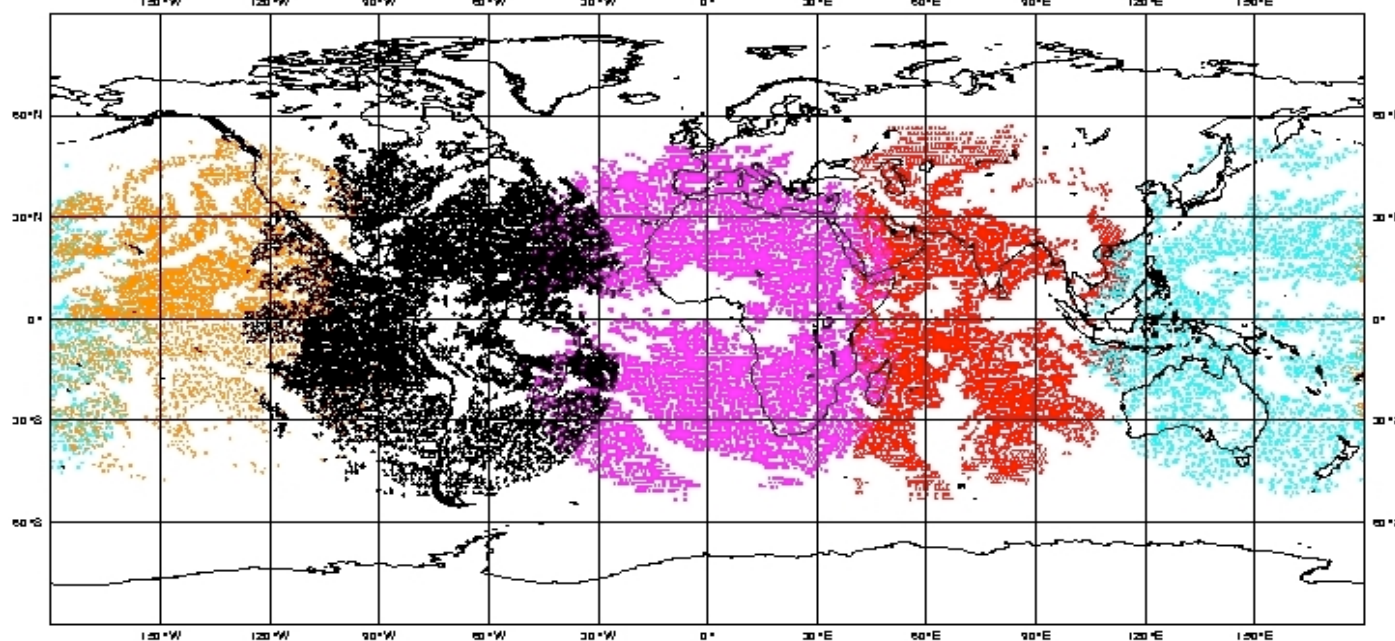
NOAA-15

NOAA-16

NOAA-17



Coverage within
A 6-hour time window



Goes-W

Goes-E

Met-7

Met-5

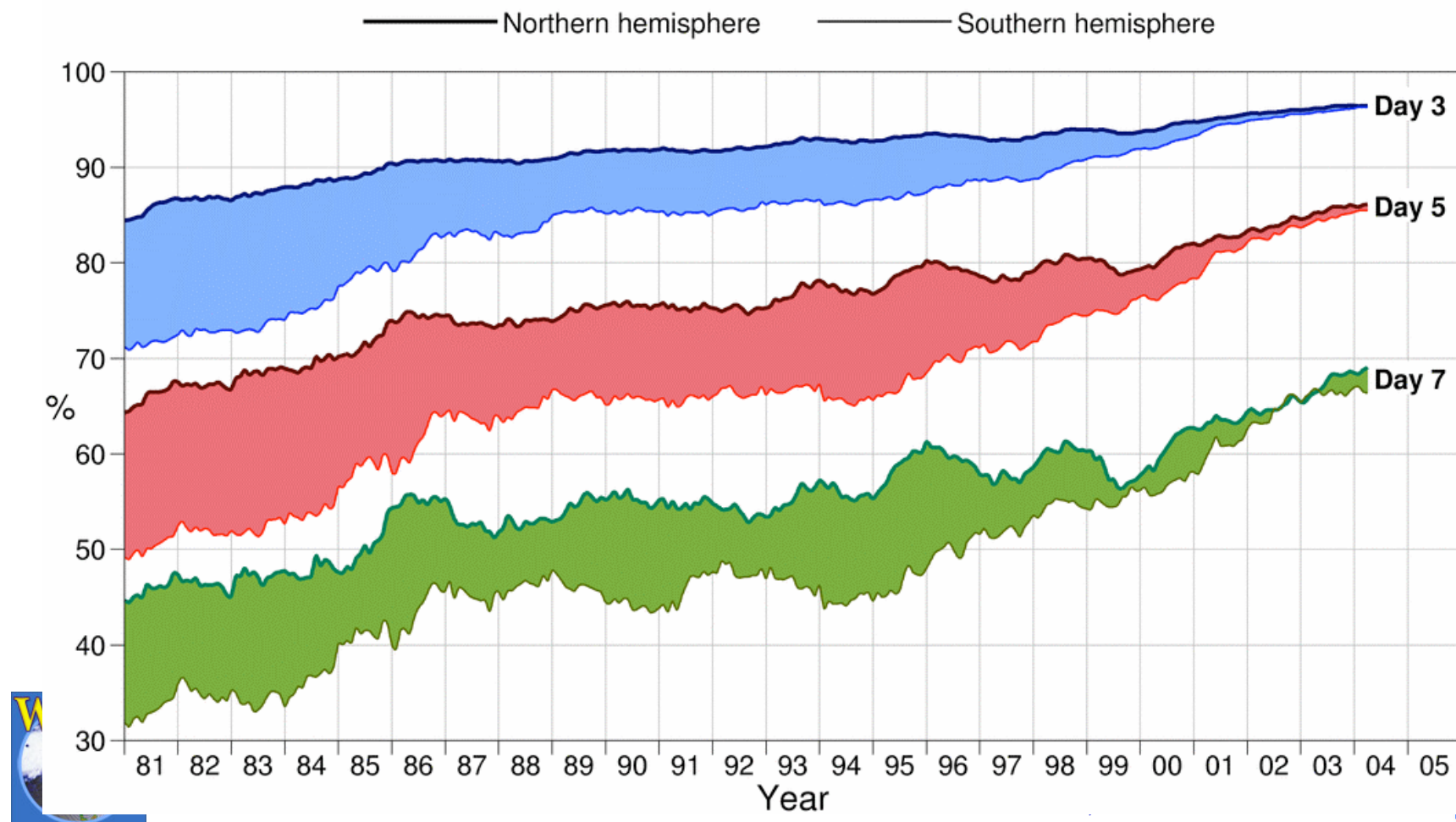
GMS(Goes-9)

2010 Winter WRF DA tutorial, Feb. 1~3

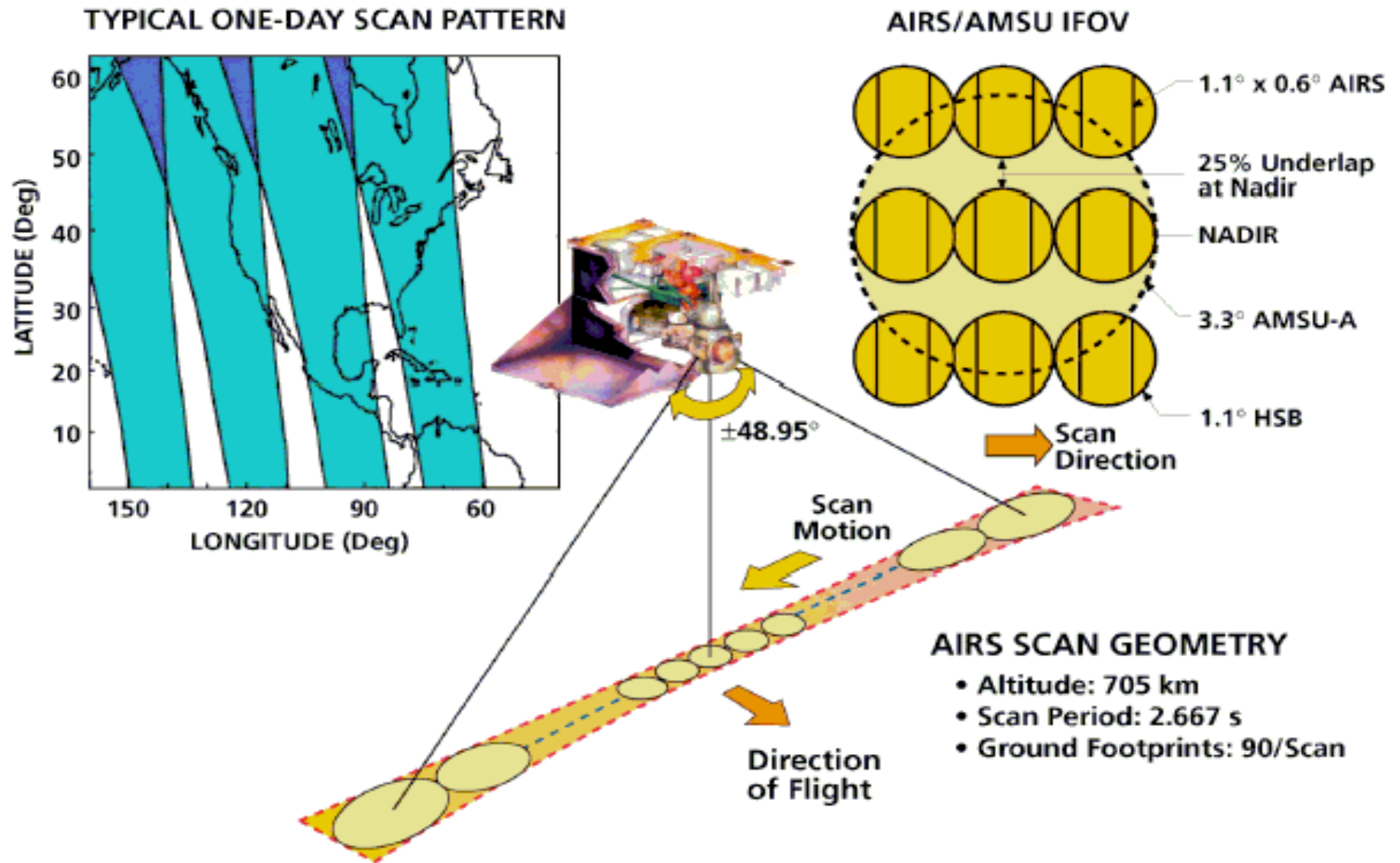
Evolution of forecast skill for northern and southern hemispheres

Courtesy, Simmons 2004

Anomaly correlation of 500hPa height forecasts



Cross-track scan geometry of satellite instruments



TMI/SSMI/SSMIS scan geometry

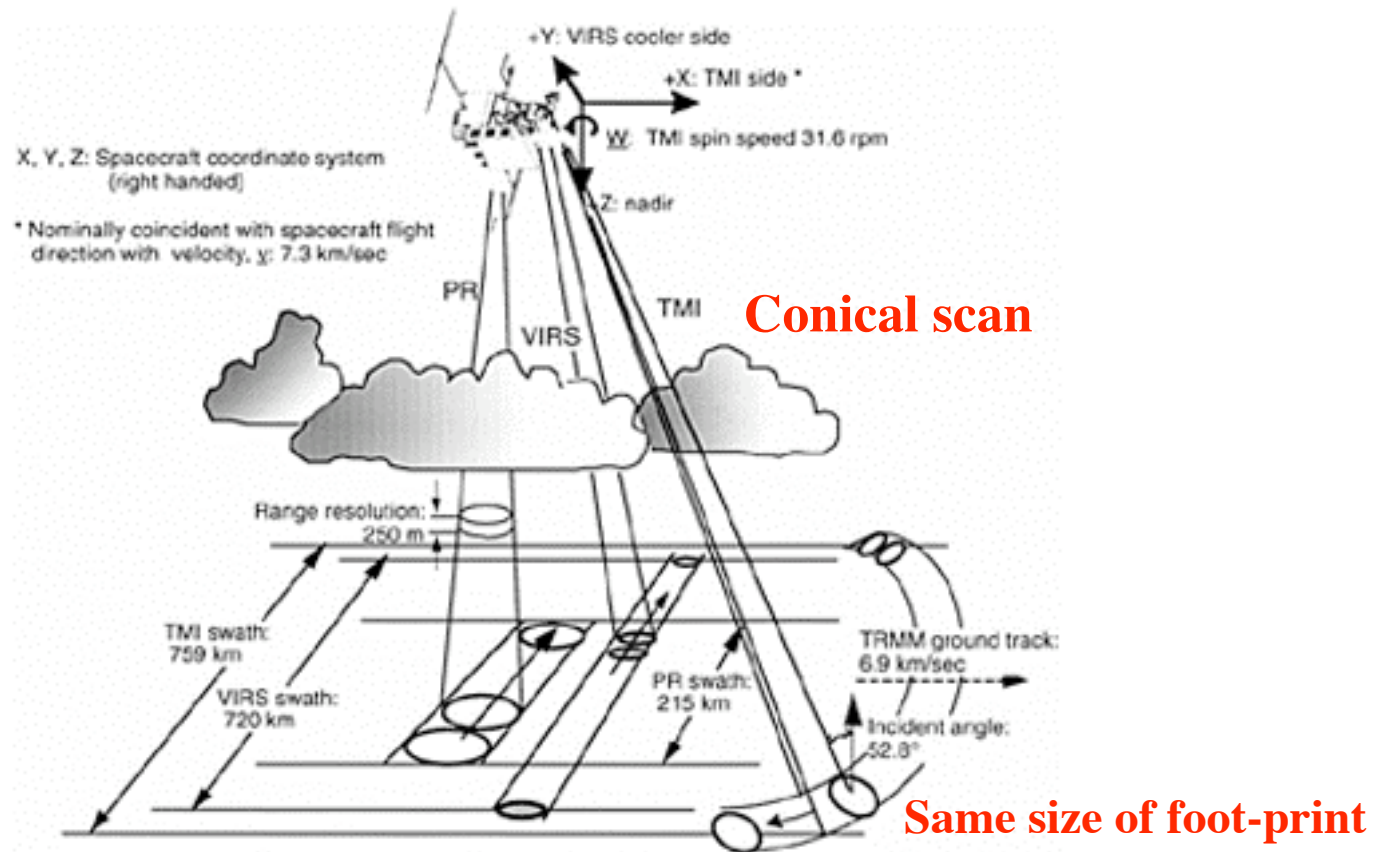


FIG. 1. Schematic view of the scan geometries of the three TRMM primary rainfall sensors: TMI, PR, and VIRS.



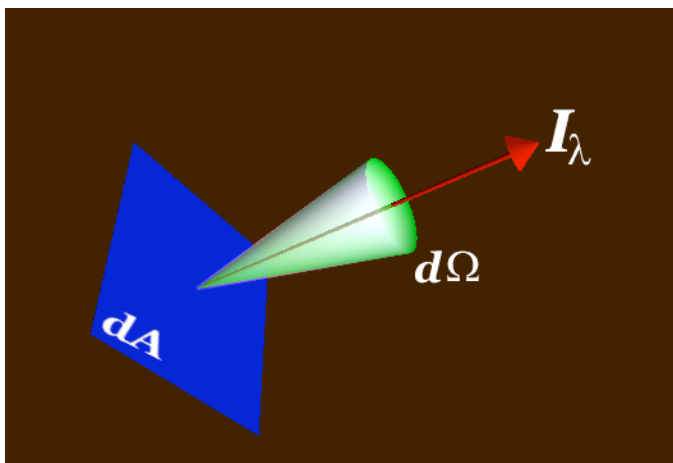
What do satellite instruments measure?

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

Satellite instruments (active and passive) simply measure the radiance L that reaches the top of the atmosphere at frequency ν . The measured radiance is related to geophysical atmospheric variables by the radiative transfer equation.

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \dots$$





Radiance:

L with $[L] = \text{Wm}^{-2}\text{sr}^{-1}\mu\text{m}^{-1}$

Planck function:

$$B_{\nu}(T) = \frac{2h\nu^3}{c^2} \left[\exp\left(\frac{h\nu}{kT}\right) - 1 \right]^{-1}$$

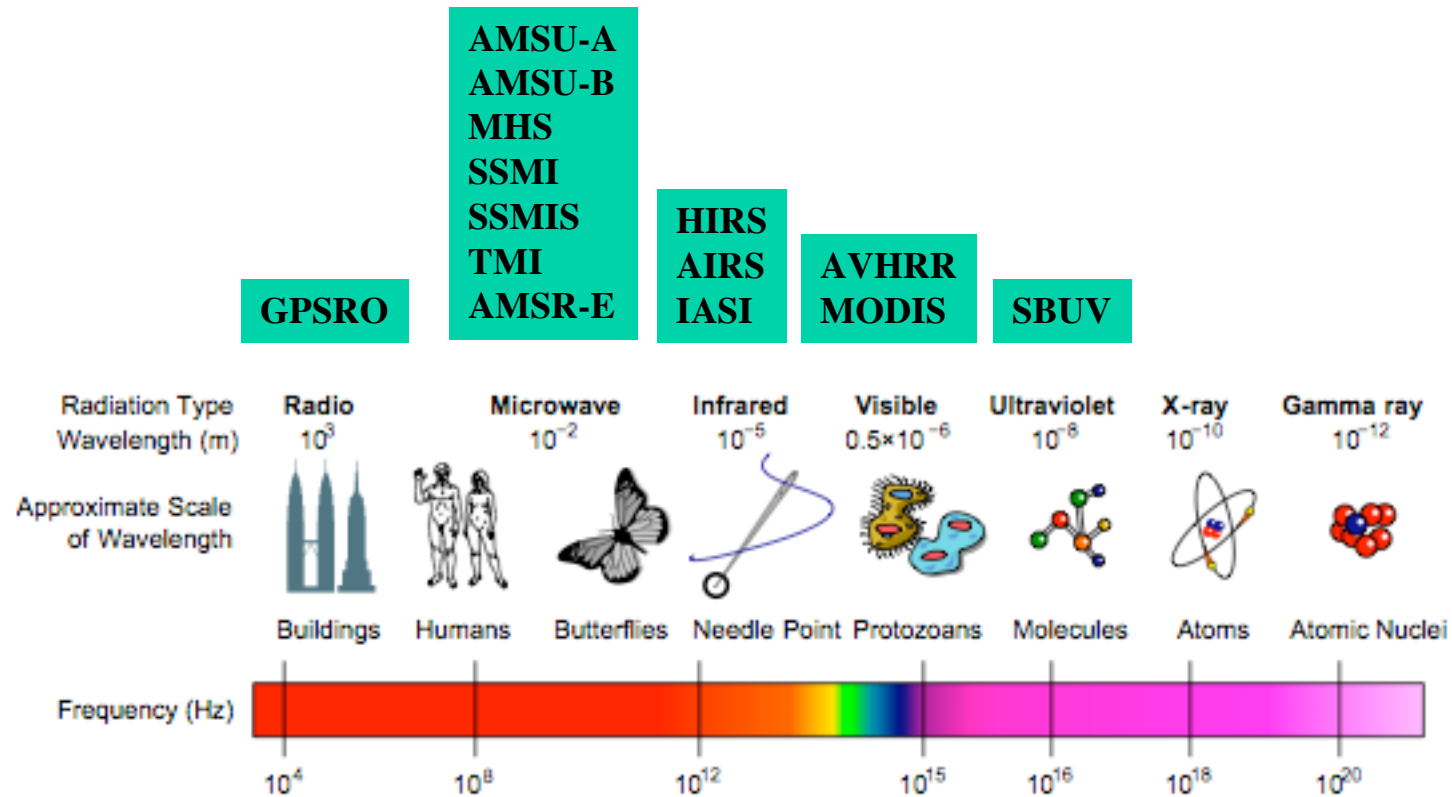
Radiance: the amount of **energy** per unit **surface** per unit **time** per unit **solid angle** emitted at the frequency ν or wavelength λ .

Brightness Temperature (in Kelvin) : the temperature that a **blackbody** would need to have in order to emit radiation of the observed radiance at a given wavelength. Also refer to as “**equivalent blackbody temperature**”. Derived by inverting the Planck function.

Usually measurements are given to the users in calibrated **Brightness Temperature**.



Sensors from Weather/Environment Satellites



Electromagnetic Spectrum



Why assimilating Radiances?

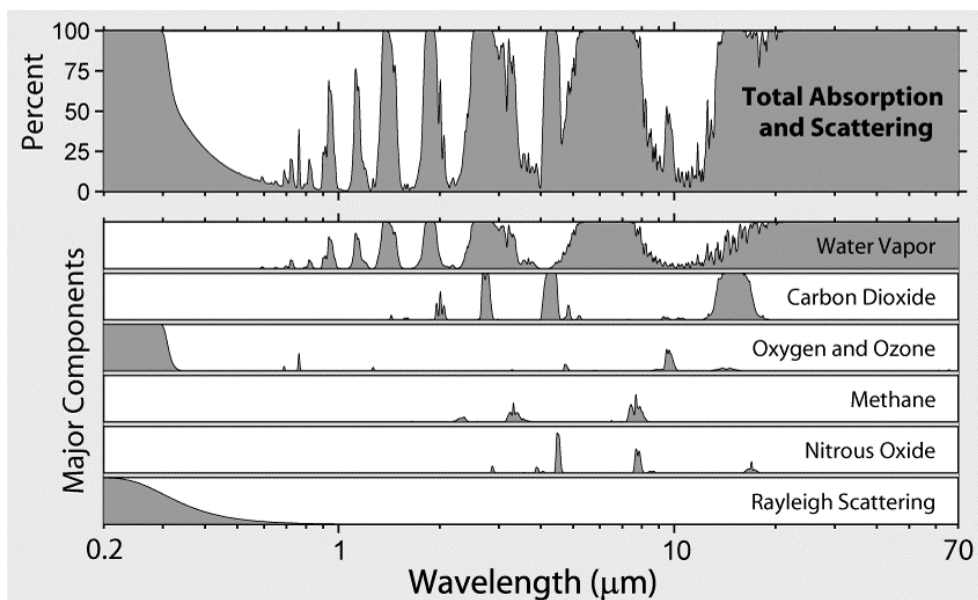
- Avoid **complicated errors** (random and systematic) introduced by (unnecessary) pre-processing such as cloud clearing, angle (limb) adjustment and surface corrections.
- Avoid having to change (retune) our assimilation system when the **data provider changes the pre-processing**
- Faster **access 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 projects



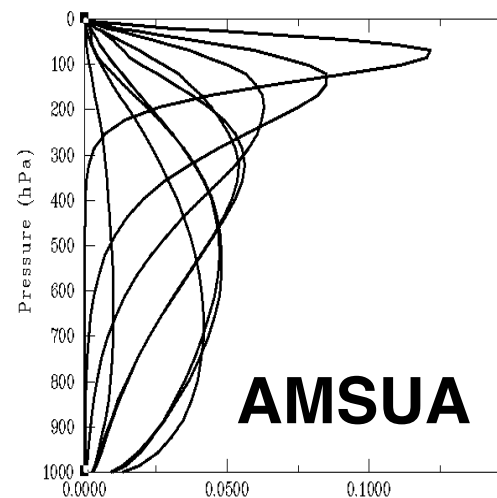
Radiative Transfer: Forward model

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface} + \text{Cloud/rain}$$

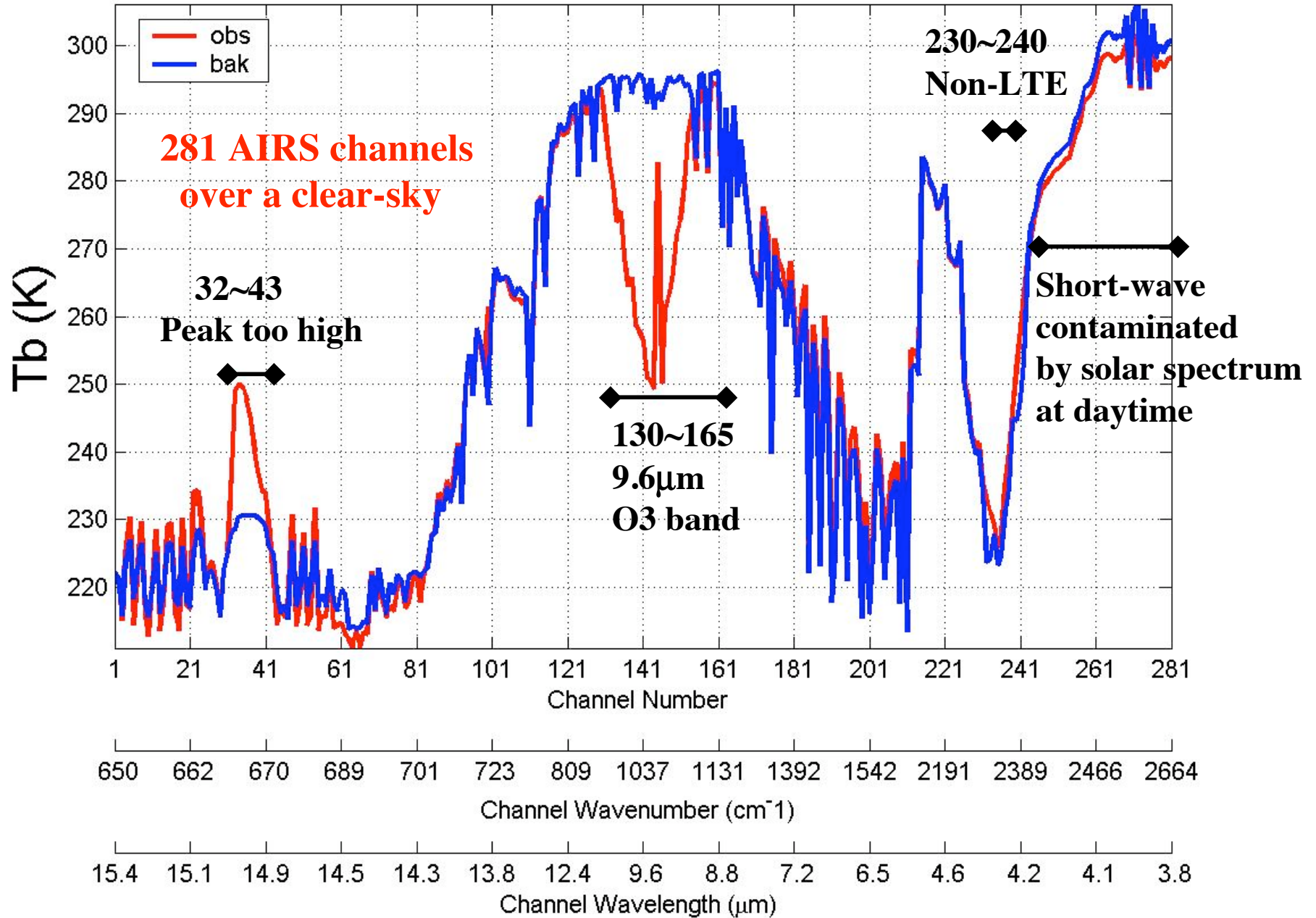
$L(\nu)$: TOA radiance at frequency ν
 $B(\nu, T(z))$: Planck function
 $\left[\frac{d\tau(\nu)}{dz} \right]$: Atmospheric absorption
 Surface: Emission/reflection
 Cloud/rain: Diffusion/scattering



- Temperature information derived from well-mixed absorbers (CO₂, ...)
- Channels sensitive to Humidity, Ozone, ...
- Surface channels: “window” parts of spectrum



P=1750 lat=23.52 lon=-73.04



Radiance Assimilation in 3D/4D-VAR

Solving the inverse problem by minimizing a cost function

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

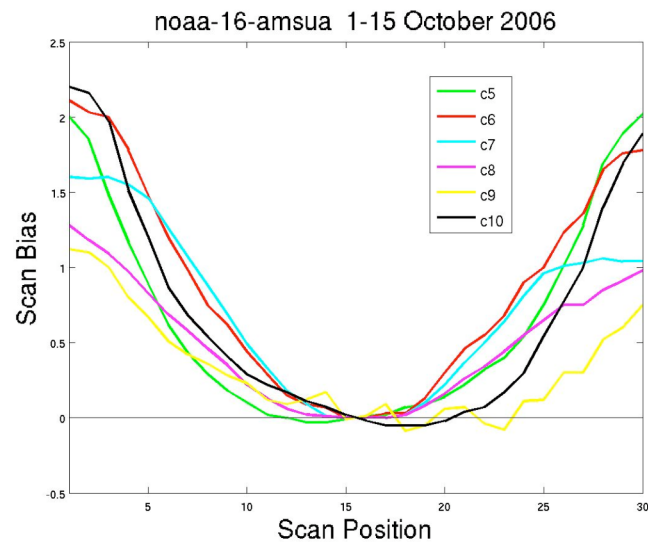
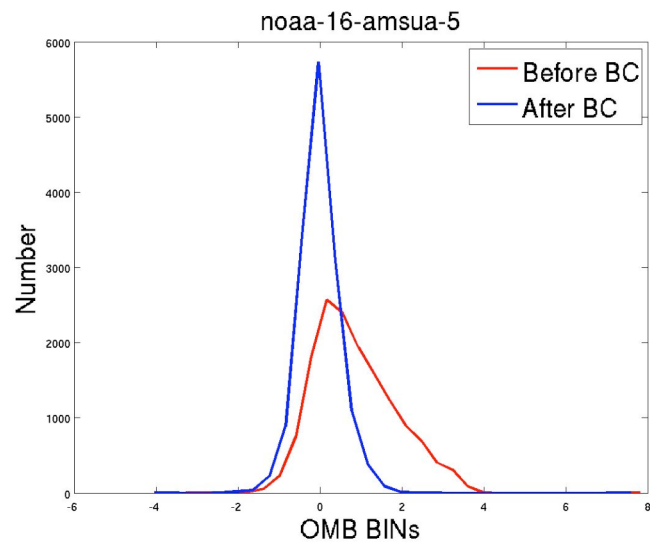
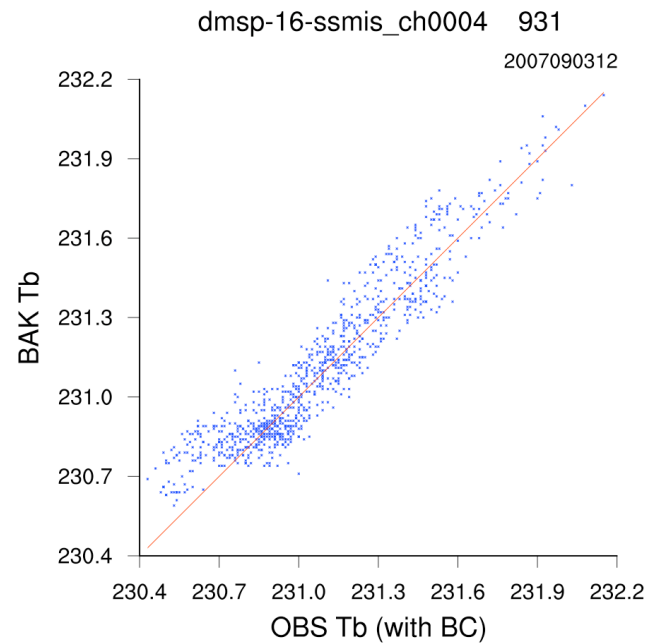
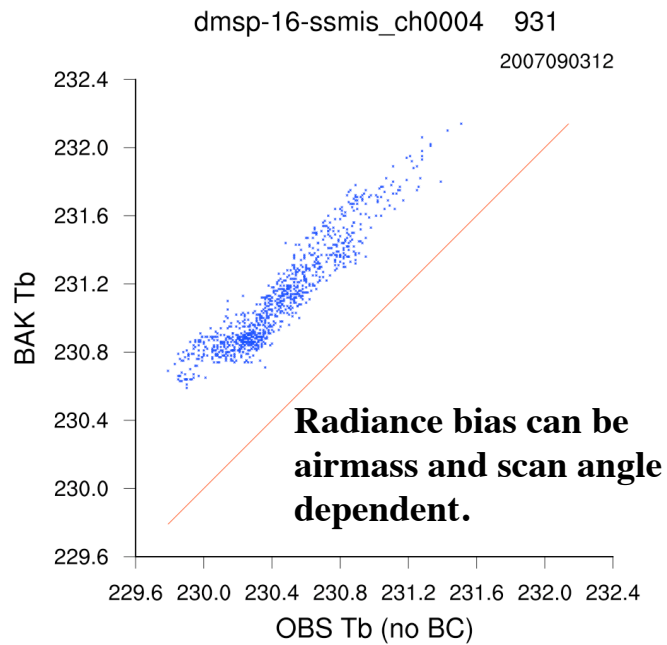


Observation operators include Radiative Transfer Model

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 correction in B.
3. Can affect no-measured quantities through multivariate correction in B.



Implementation: Handling Radiance Bias



Implementation: Variational Bias Correction

(Thomas Auligne)

Modeling of errors in satellite radiances:

$$y = H(x_t) + B(\beta) + \varepsilon$$

$$\left\{ \begin{array}{l} \langle \varepsilon \rangle = 0 \\ B(\beta) = \sum_{i=1}^N \beta_i p_i \end{array} \right.$$

Parameters

Predictors:

- Offset
- 1000-300mb thickness
- 200-50mb thickness
- Surface skin temperature
- Total column water vapor
- Scan

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 : background term for x
 J_o : corrected observation term

$$J(x, \beta) = \underbrace{(x_b - x)^T B_x^{-1} (x_b - x)}_{J_b: \text{background term for } x} + \underbrace{[y - H(x) - B(\beta)]^T R^{-1} [y - H(x) - B(\beta)]}_{J_o: \text{corrected observation term}} + \underbrace{(\beta_b - \beta)^T B_\beta^{-1} (\beta_b - \beta)}_{J_\beta: \text{background term for } \beta}$$

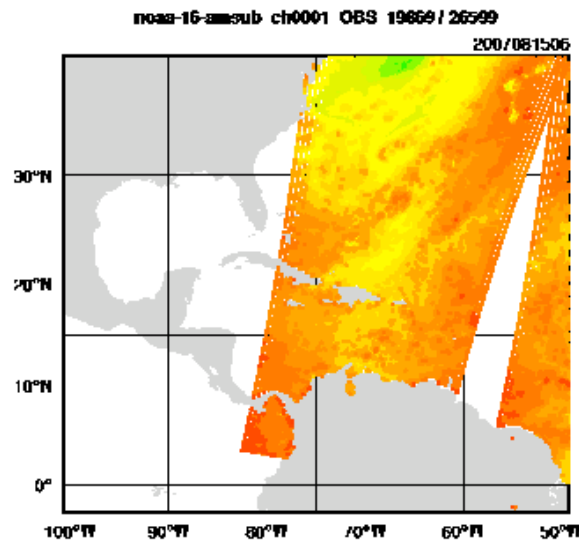
«Optimal » bias correction considering all available information



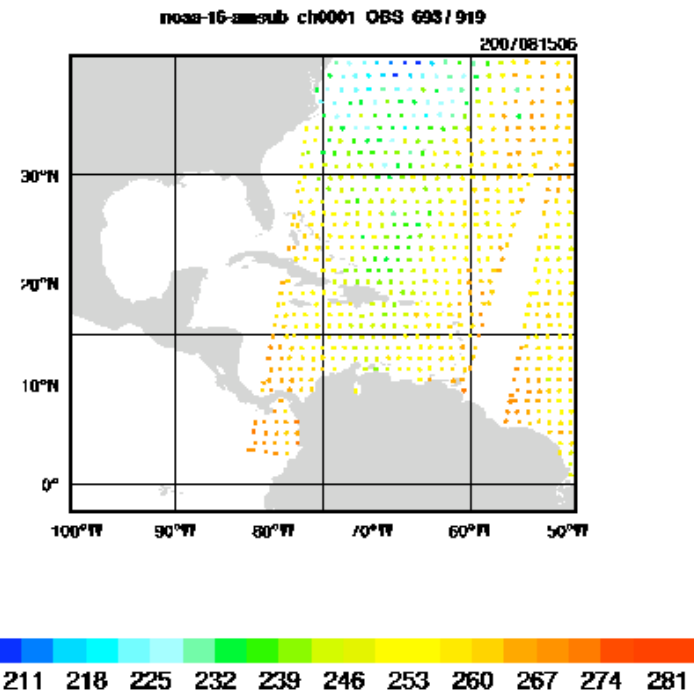
Implementation: Thinning

Dense data are very likely correlated, which is not taken into account in the observation covariance matrix R .

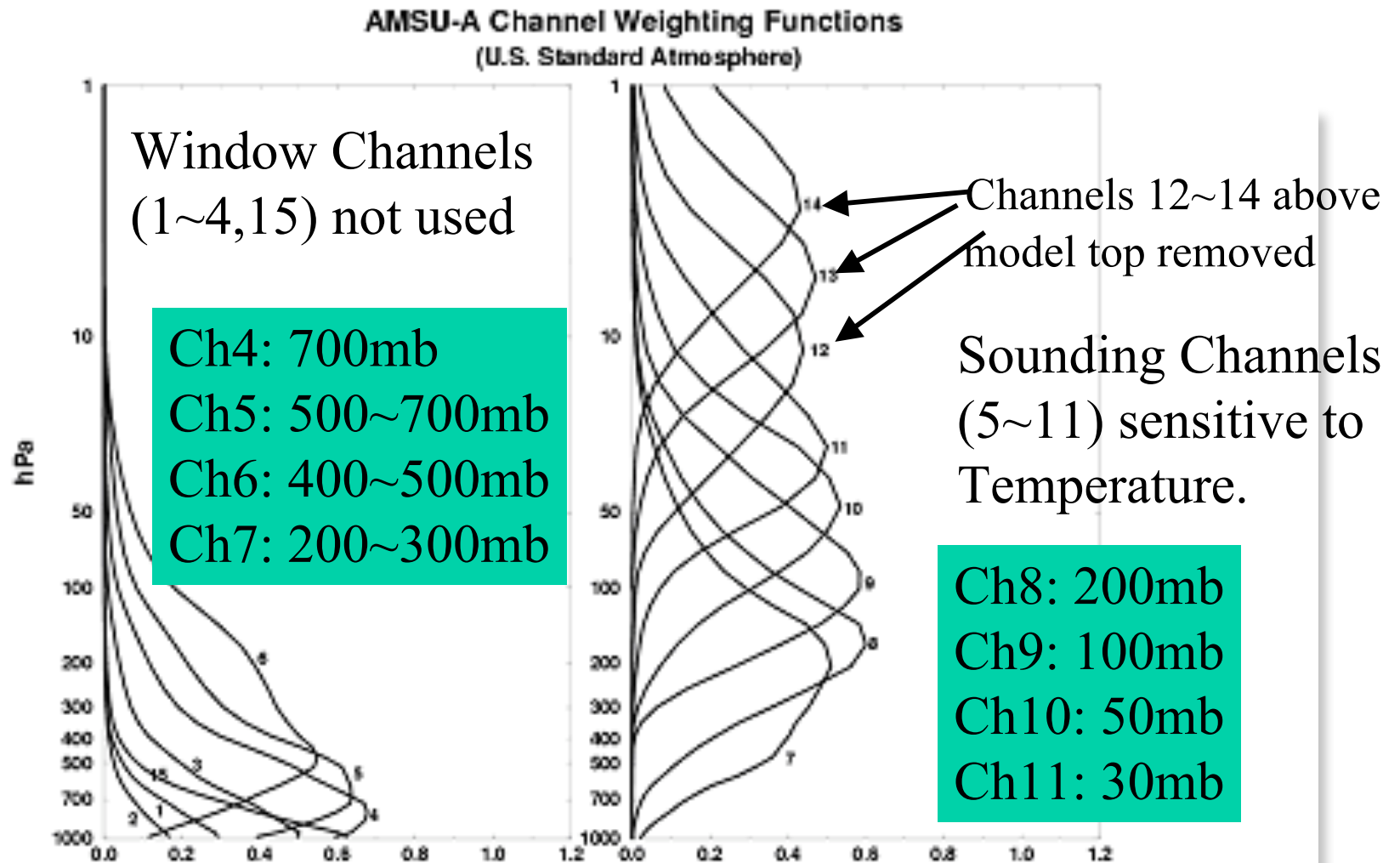
No Thinning



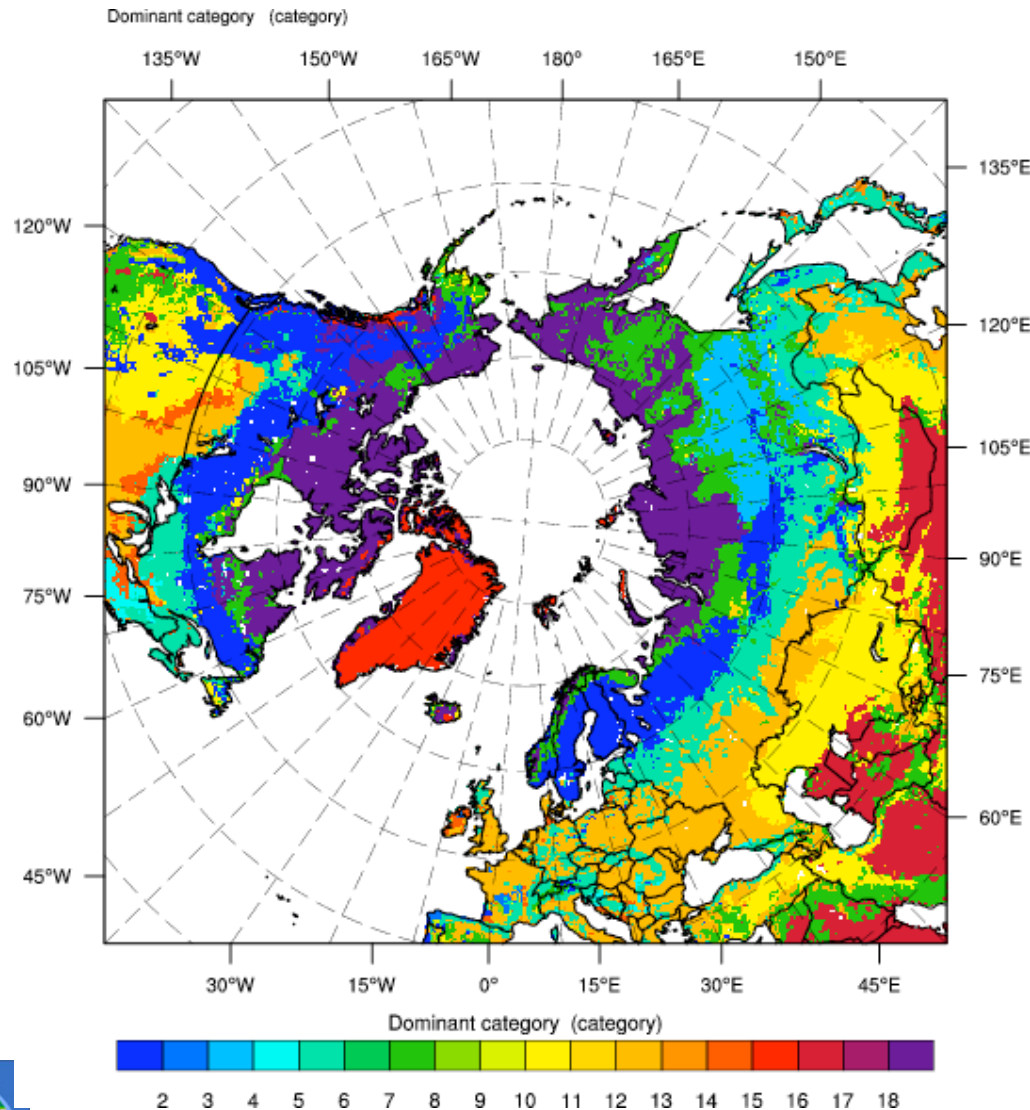
120km Thinning Mesh



Implementation: Channel selection



Application: Arctic System Reanalysis



10mb model top
71 Levels
30km grid-spacing

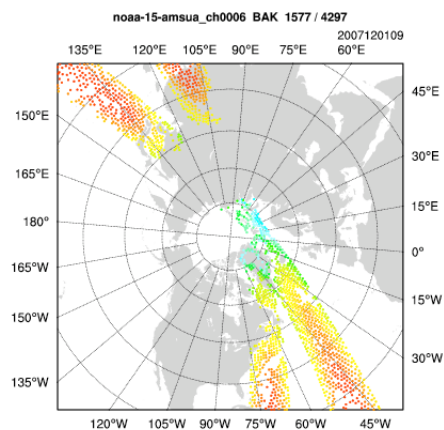
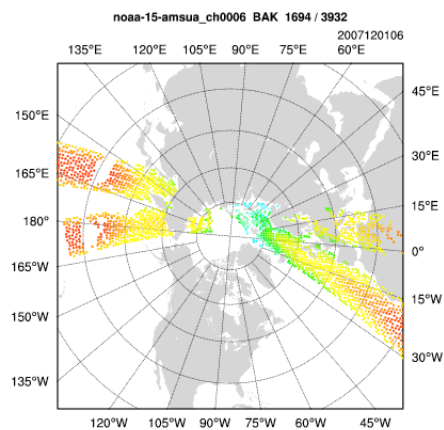
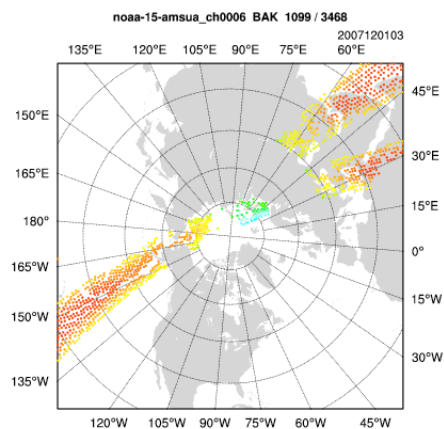
ERA-Interim as
LBC

3-hourly 3DVAR
Cycling

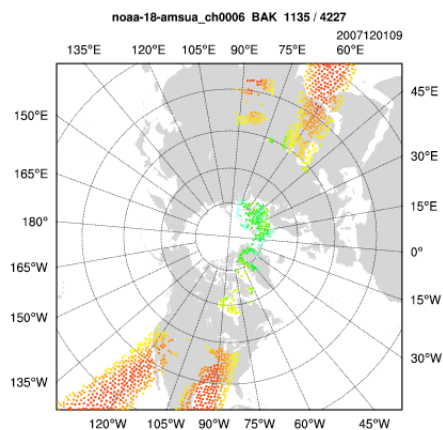
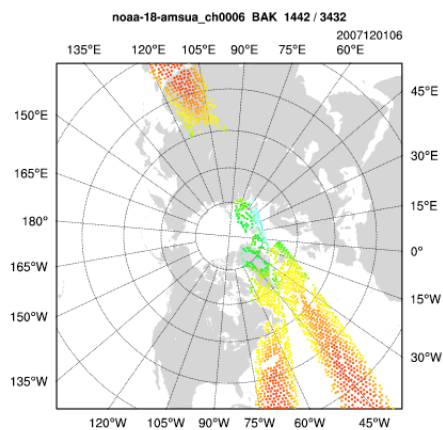
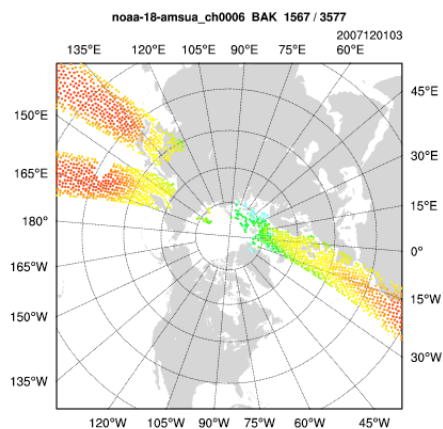
Assimilate 10 MW
Sensors.



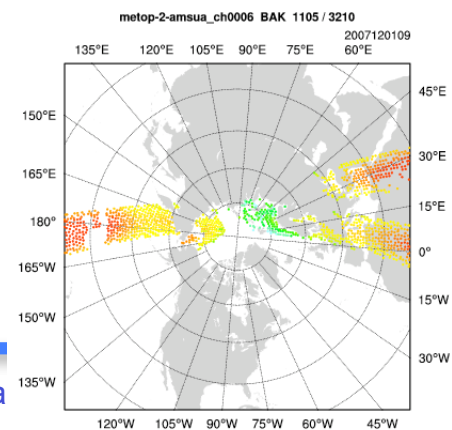
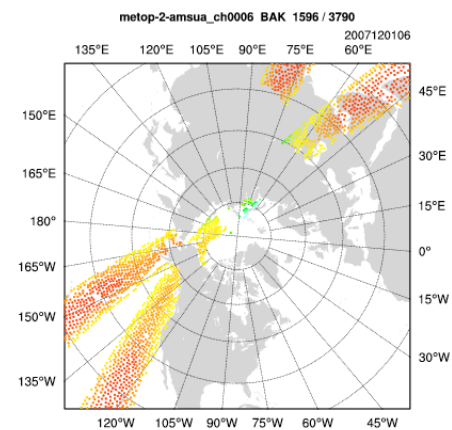
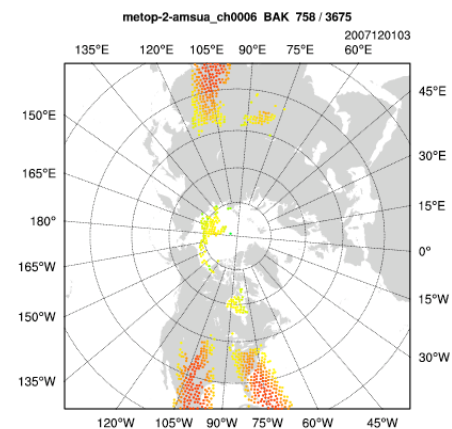
noaa-15-amsua



noaa-18-amsua

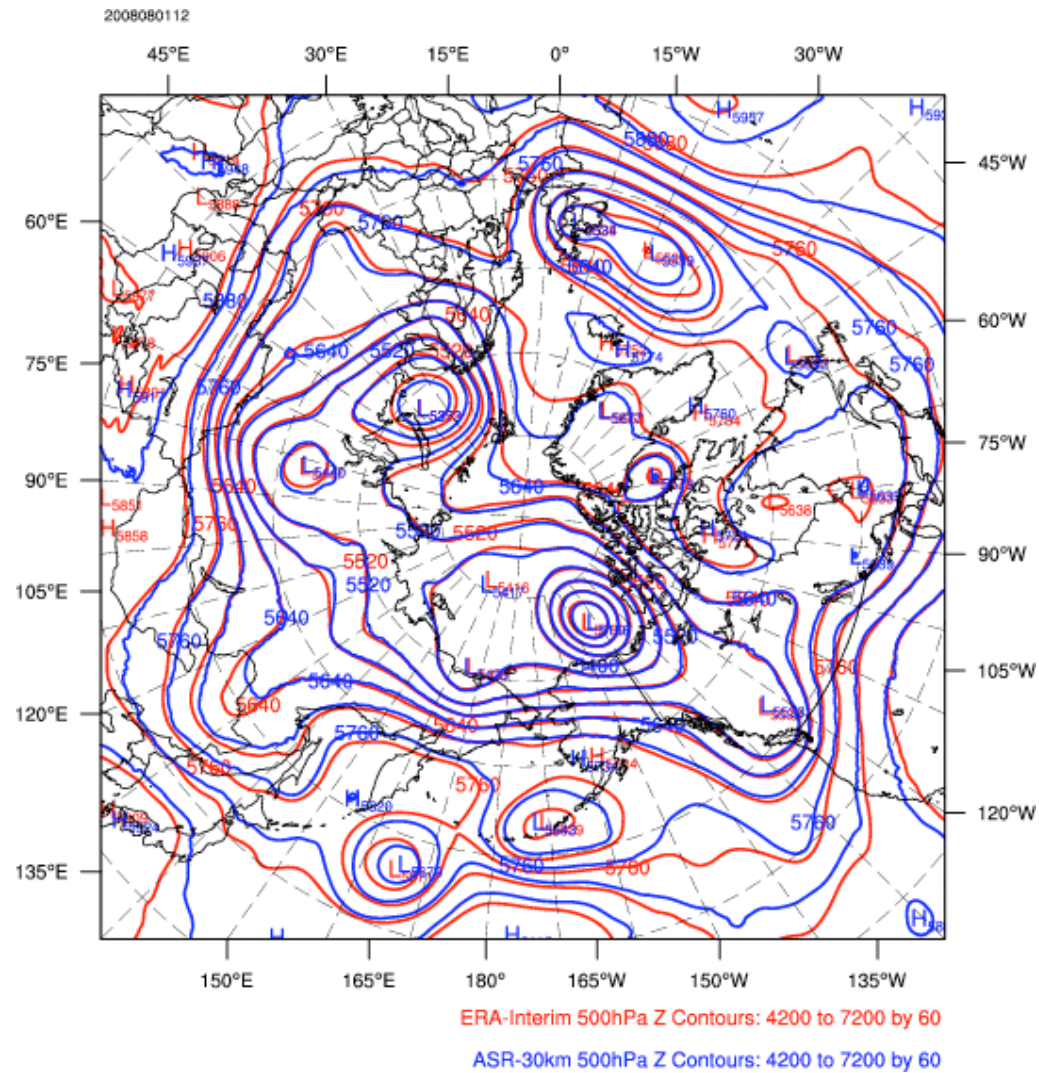


metop-2-amsua



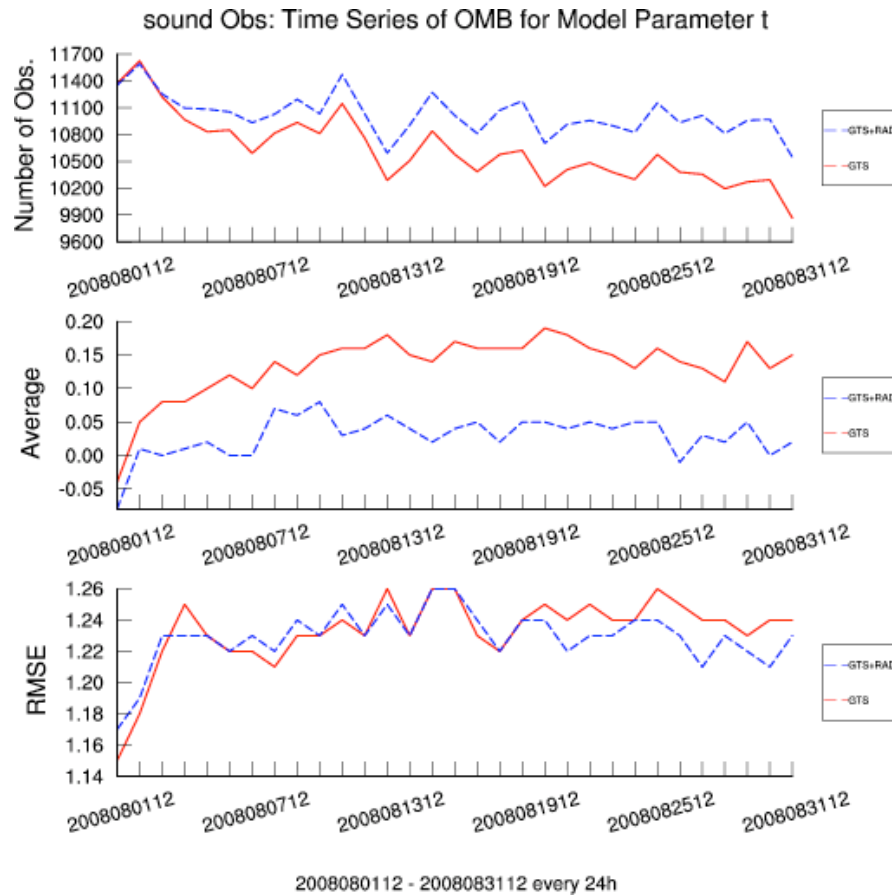
DA tutoria

500 hPa geo-potential height analysis at 00Z/12Z Aug. 2008

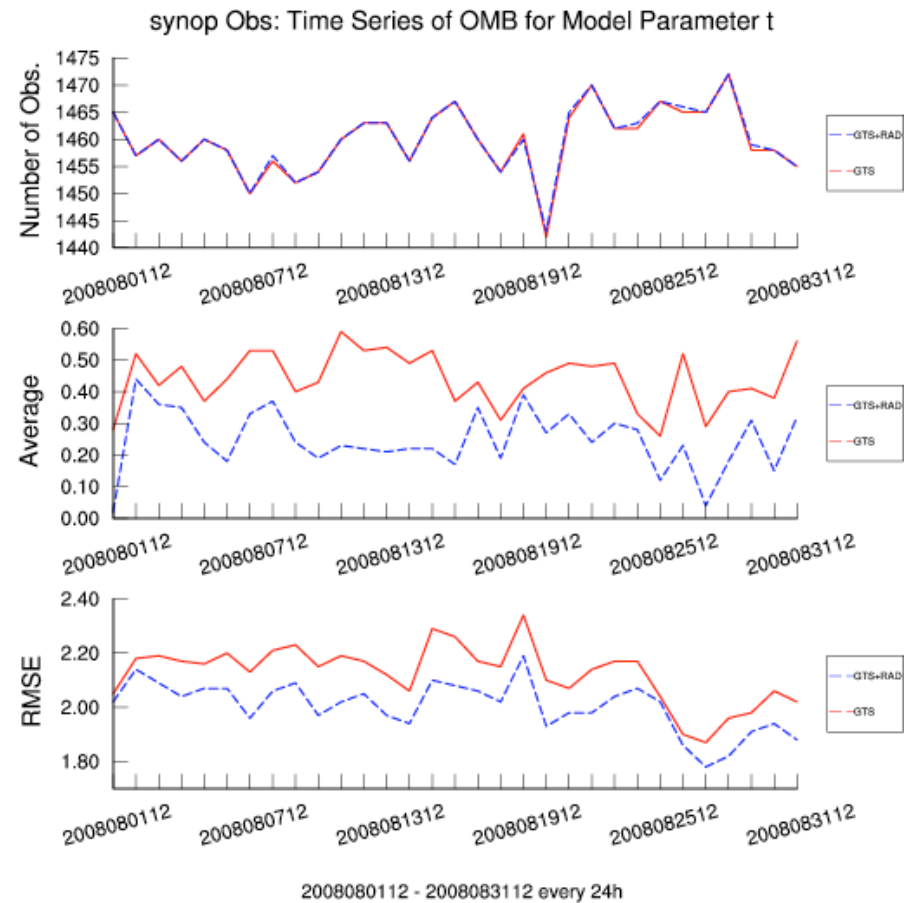


Time Series of Obs minus Background

Sounding T



SYNOP T



Part II: Practice with WRF-Var

- **Data Ingest (sources, instruments)**
- **Radiative transfer model**
- **Channel selection**
- **Variational Bias correction**
- **Diagnostics and monitoring**



Data Ingest

- NCEP global BUFR format radiance data within a 6h time window (Total: 15 sensors from 6 satellites)
 - **4 HIRS** from NOAA16, 17, 18, METOP-2
 - **5 AMSU-A** from NOAA15, 16, 18, EOS-Aqua, METOP-2
 - **3 AMSU-B** from NOAA15, 16, 17
 - **2 MHS** from NOAA18, 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

[ftp://ftp.ncep.noaa.gov/pub/data/nccf/com/gfs/prod/gdas.\\${yyyymmddhh}](ftp://ftp.ncep.noaa.gov/pub/data/nccf/com/gfs/prod/gdas.${yyyymmddhh})

NOAA Historical archive: <http://nomads.ncdc.noaa.gov/>

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

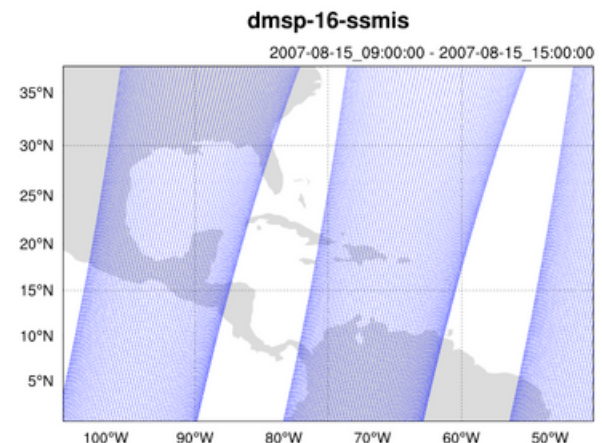
amsua.bufr
amsub.bufr
hirs3.bufr
hirs4.bufr
mhs.bufr
airs.bufr

Direct input to WRF-Var, 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)

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

Latest released version: CRTM REL-1.2.1,

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

1=RTTOV (Radiative Transfer for TOVS)

EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)

<http://www.metoffice.gov.uk/research/interproj/nwpsaf/rtm/index.html>

Latest released version: RTTOV_9_3,

Version used in WRF-Var: RTTOV_8_7 (no plan/resource to update to RTTOV_9)



Channel selection and error specification

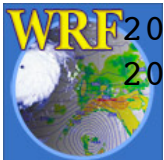
```
WRFDA/var/run/radiance_info>ls -l
```

```
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    391 Aug 22 17:01 noaa-17-amsub.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

sensor	channel	IR/MW	use	idum	varch	polarisation(0:vertical;1:horizontal)
203	1	1	-1	0	0.2500000000E+01	0.0000000000E+00
203	2	1	-1	0	0.2500000000E+01	0.0000000000E+00
203	3	1	1	0	0.2500000000E+01	0.1000000000E+01
203	4	1	1	0	0.2000000000E+01	0.1000000000E+01
203	5	1	1	0	0.2000000000E+01	0.0000000000E+00



Setup and run WRF-Var with radiances

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

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

In -sf WRFDA/run/LANDUSE.TBL ./LANDUSE.TBL

In -sf \$DAT_DIR/rc/2007010200/wrfinput_d01 ./fg (link first guess file as fg)

In -sf WRFDA/var/obsproc/obs_gts_2007-01-02_00:00:00.3DVAR ./ob.ascii (link OBSPROC processed
observation file as ob.ascii)

In -sf \$DAT_DIR/be/be.dat ./be.dat (link background error statistics as be.dat)

In -sf WRFDA/var/da/da_wrfvar.exe ./da_wrfvar.exe (link executable)

In -sf \$DAT_DIR/2007010200/gdas1.t00z.1bamua.tm00.bufr_d ./amsua.bufr

In -sf ~WRFDA/var/run/radiance_info ./radiance_info

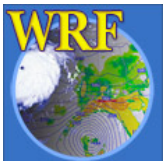
(CRTM only) In -sf \$CRTM_COEFFS_DIR ./crtm_coeffs

(RTTOV only) In -sf \$RTTOV_COEFFS_DIR/rtcoef*.dat ./rtcoef*.dat

In -sf ~WRFDA/var/run/VARBC.in .

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 = 12
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
```

NOAA-15-AMSUA
NOAA-16-AMSUA
NOAA-18-AMSUA
EOS-2-AMSUA
METOP-2-AMSUA
NOAA-15-AMSUB
NOAA-16-AMSUB
NOAA-17-AMSUB
NOAA-18-MHS
METOP-2-MHS
EOS-2-AIRS
DMSP-16-SSMIS

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

**Internal convert b.w. CRTM&RTTOV
Convention is invisible to users.**

**This facilitates the user’s config.
When switch b.w. two RTMs.**



more sensors supported, from RTTOV_8_7 Users Guide

http://www.metoffice.gov.uk/research/interproj/nwpsaf/rtm/rttov8_ug.pdf

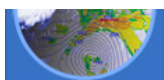
Instrument triplets platform_id
satellite_id
sensor_id

platform_id satellite_id

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
COROLIS	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_id

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 be.

CRTM coefficients

After untarring

ftp://ftp.emc.ncep.noaa.gov/jcsda/CRTM/REL-1.2/REL-1.2.Coeffs.JCSDA_CRTM.tar.gz

```
CRTM_Coefficients>ls -l
```

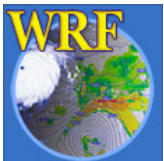
```
drwxr-xr-x    5 hclin    ncar   8192 Feb 06 15:48 AerosolCoeff
drwxr-xr-x    5 hclin    ncar   8192 Feb 06 15:48 CloudCoeff
drwxr-xr-x    5 hclin    ncar   8192 Feb 06 15:48 EmisCoeff
drwxr-xr-x    5 hclin    ncar   8192 Feb 06 15:48 SpcCoeff
drwxr-xr-x    5 hclin    ncar   8192 Feb 06 15:48 TauCoeff
```

Each *Coeff has 3 subdirectories containing coefficient files in different format.
Big_Endian (binary) files are used in WRF-Var.

```
CRTM_Coefficients/SpcCoeff>ls -l
```

```
drwxr-xr-x    2 hclin    ncar  16384 Feb 06 15:48 Big_Endian
drwxr-xr-x    2 hclin    ncar  16384 Feb 06 15:48 Little_Endian
drwxr-xr-x    2 hclin    ncar  16384 Feb 06 15:48 netCDF
```

Link selected files from *Coeff/Big_Endian directories into a single directory, then link the directory as **crtm_coefs** in the WRF-Var working directory



More namelist variables

RAD_MONITORING (30): Integer array with dimension RTMINIT_NSENSOR, 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.

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.

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

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

USE_VARBC=true

freeze_varbc=false

varbc_factor=10. (for scaling the VarBC preconditioning)

varbc_nobsmin=100. (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)

crtm_atmosphere=1~6 (specify climate profile above model top. 1: Tropical2: Midlatitude summer3: Midlatitude winter4: Subarctic summer5: Subarctic winter6: U.S. Standard Atmosphere)



Variational Bias Correction (VarBC)

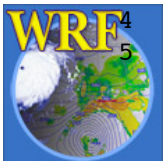
VARBC.in file is an ASCII file that controls all of what is going into the VarBC.

Sample VARBC.in

**Cold start from an empty coeffs file
For the first cycle**

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  
    10000    10000    10000    10000    10000    10000    10000    10000  
-----> 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  
    10000    10000    10000    10000    10000    10000    10000    10000  
-----> 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
```



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	0.008	-0.230	-0.111	-0.024
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

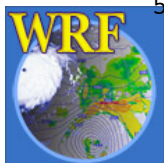
1 16 4 5 8

-----> 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



Radiance output Post-Processing/Visualization (Hui-Chuan Lin)

- `~WRFDA/var/scripts/da_rad_diags.ksh`
 - WRF-Var 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.



Consider diurnal cycle or descending/ascending orbit issue with VarBC for regional applications

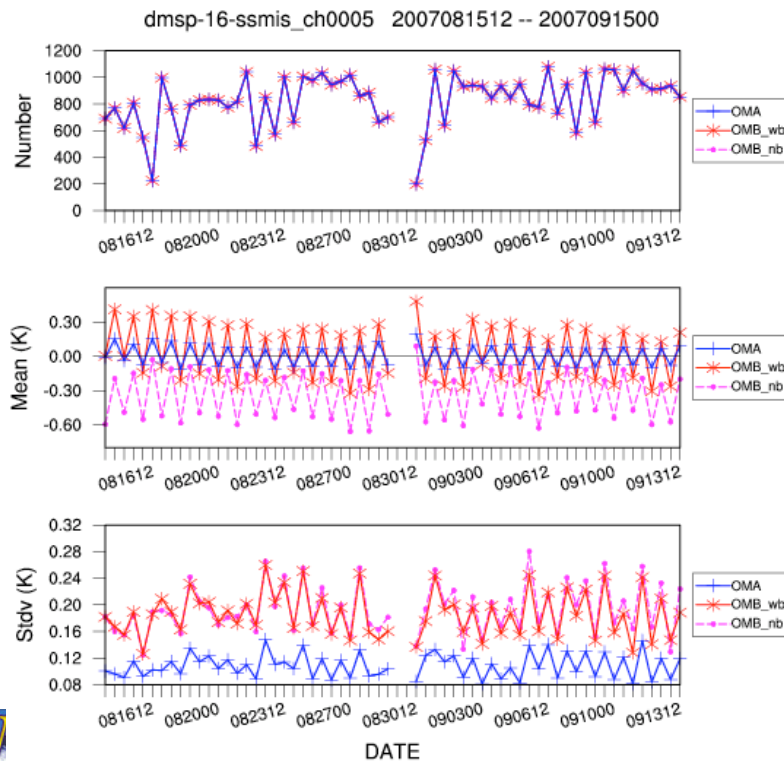
Bias with diurnal cycle.

Morning (12Z): -0.60K

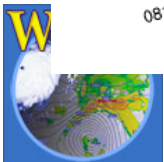
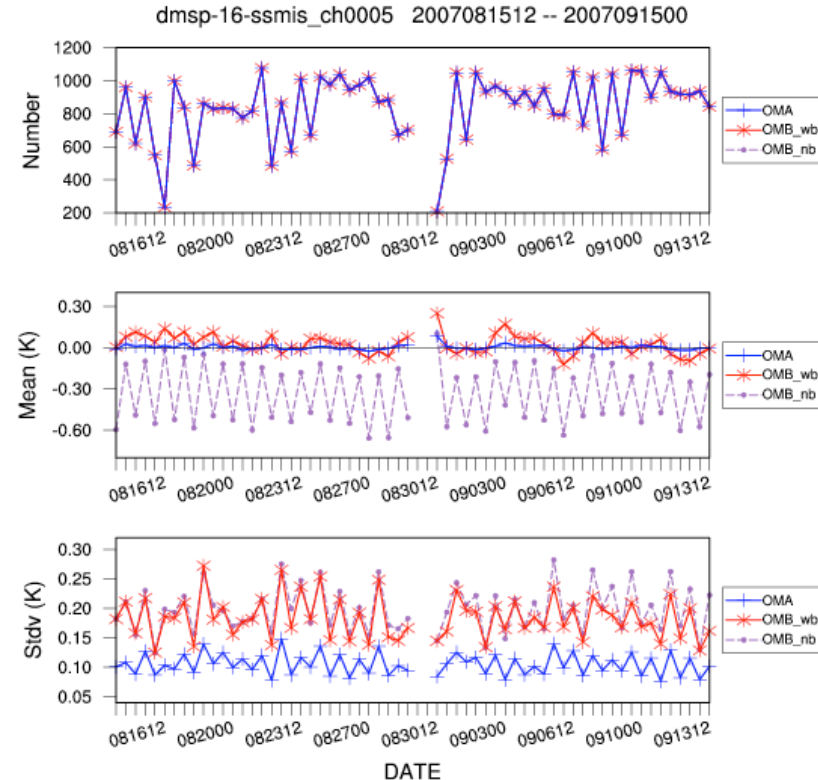
Evening (00Z): -0.15K

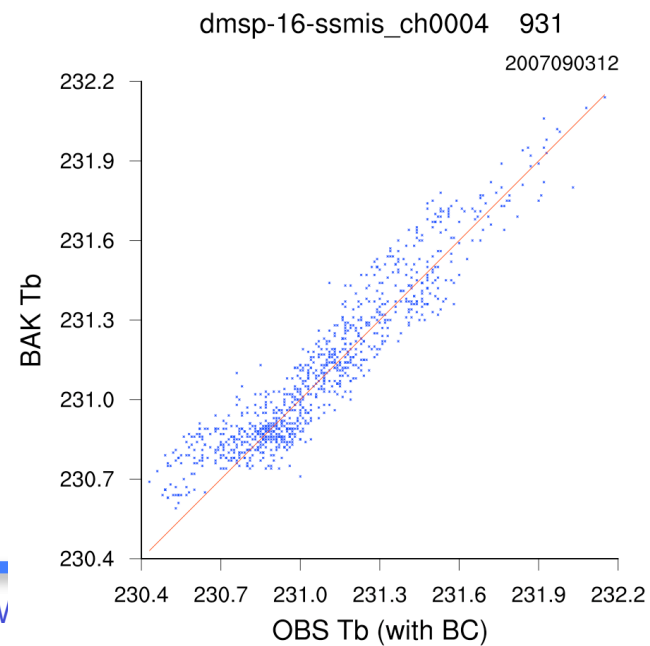
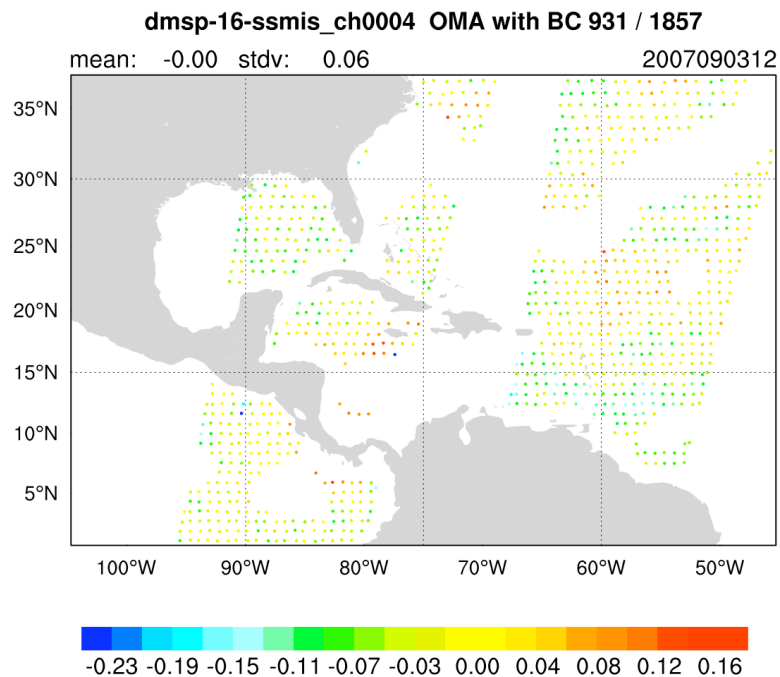
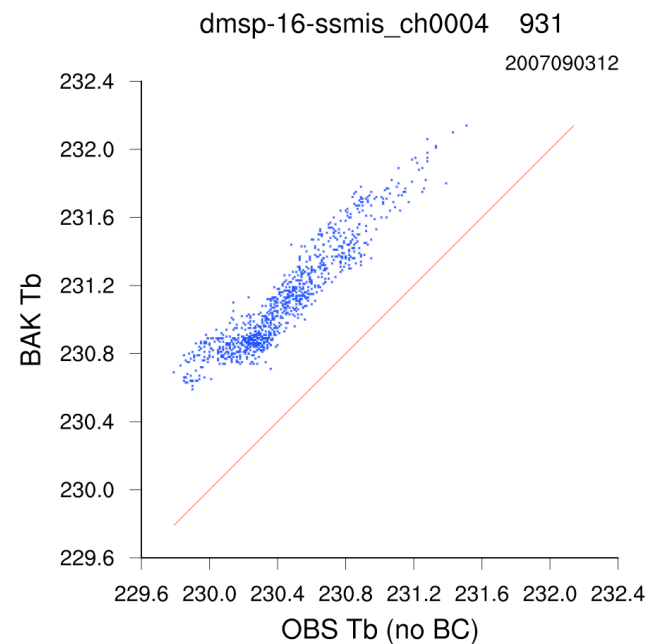
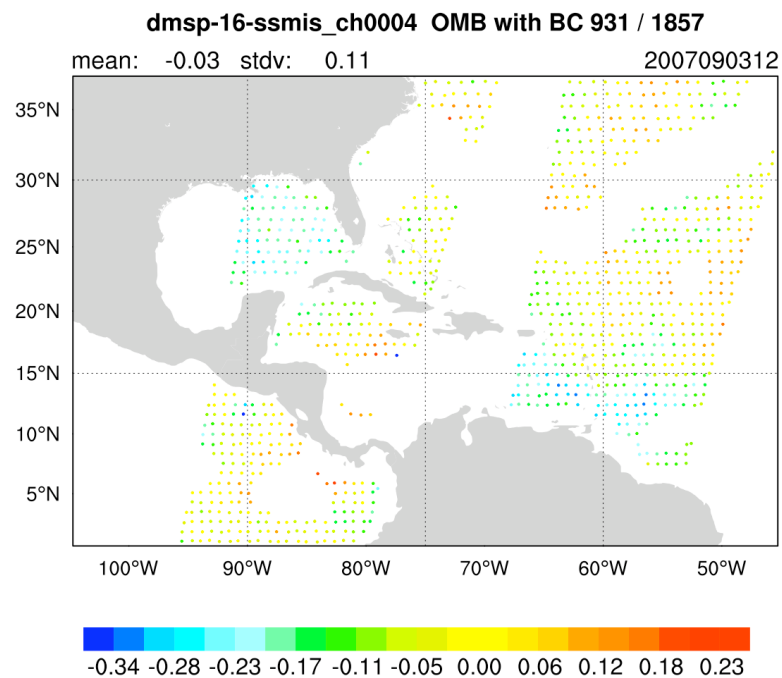
(Related to Descending/Ascending nodes)

Use one set of BC coefs for 00Z/12Z
(oscillation still exists after BC)



Use separated BC coefs for 00Z/12Z
(Oscillation is removed after BC)





10 V

Conclusions

- **Radiance data assimilation are important**
 - Major source of information within observations for global NWP
 - Positive impact on Limited Area Models
- **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, ...)
- **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**
 - There are radiance DA test cases for your play.



Questions

