Generation of a Data Base of TOA Spectral Radiance Fields

Nicolas Clerbaux

9th July 2004

Ref : MSG-RMIB-GE-TN-0030

Abstract

This technical note describes the generation, using the SBDART radiative transfer model, of a large data base of spectral radiance fields at the top of the atmosphere. This data base is of great importance to parameterize some subsystems within the GERB processing at RMIB (for instance spectral modeling or the unfiltering).

Contents

1   Introduction

Utility of the database

For the GERB ground segment development and parameterization, a **large** data set of
realistic Earth-atmosphere spectral radiance curves is needed. This data set is necessary:

- to develop, parameterize and validate the spectral modeling parts of the GERB
  ground segment: unfiltering of the GERB filtered radiances and estimate of high
  resolution broadband radiances using the imaging device.

- to develop, parameterize and validate some parts of the scene identification,

- to develop, parameterize and validate some parts of the angular conversion (only
  thermal) .

This data base should contain the extreme conditions that could be encountered for the
Earth/atmosphere system. So, the typical ranges of variation for the physical parameters
are enlarged voluntary.

The SBDART radiative transfer code (RTC) has been choose to generate this data base.
Some basics about this RTC are available in [3].

The next section describes the random generation of SBDART input. Section 3 describes
the programs used to launch SBDART. The last sections (4 and 5) present some utility
programs and the program used to spectrally convolute the data base with the spectral
response filters of different radiometers.

Localization of the programs

The main programs and scripts, some tools, the program to convolute with some instrument
SR curves and the resulting database are located in the following directories:

```
/wind/nic/RadiaTrans/MakeCurves  -> creation
/wind/nic/RadiaTrans/Util        -> test, ....
/wind/nic/RadiaTrans/Convol      -> convolution
/winddata/nic/RadiaTrans         -> data
```

Web Access

The data base and the related documentation is available at the following web address:

```
http://gerb.oma.be/nic/SpectralRadiancesDB
```

2 SBDART inputs

Surface characteristics

Surface spectral albedo (solar only)

In the solar reflected region, the surface is characterized by its spectral albedo curves $\rho(\lambda)$. This curve is generated by SBDART itself using a weighted combination of 4 reference curves:

$$\rho(\lambda) = c_0\,\rho_0(\lambda) + c_1\,\rho_1(\lambda) + c_2\,\rho_2(\lambda) + c_3\,\rho_3(\lambda)$$

The SBDART internal spectral reflectance curves are:

$\rho_0(\lambda)$	snow surface
$\rho_1(\lambda)$	ocean surface
$\rho_2(\lambda)$	sand surface
$\rho_3(\lambda)$	vegetated surface

The program `makesurface.c` is used to generate a file that contains the $\{c_i\}$ values. This program first chooses randomly the number of non-null c_i values with the probabilities:

number of non-null c_i	probability
1	20%
2	40%
3	20%
4	20%

Then the non-null c_i values are chosen randomly with probabilities given in table hereafter until the wanted number of non-null c_i values is reached:

i	class	probability
0	snow	10%
1	ocean	40%
2	sand	20%
3	vegetation	30%

Then, the non-null c_i are chosen randomly in the range $[0,1]$ and are normalized by their sum $c = \Sigma c_i$. The n, all the c_i are multiply by a random factor in the range $[0.5, 1.5]$ (the same factor is used for all the c_i). So, the sum c of the weighting factors c_i lies in the range $c \in [0.5, 1.5]$.

The results are stored in the file **surface.txt** for 3000 different surfaces. The more represented classes are:

class	probability
mix snow-ocean-sand-vege	20%
mix ocean-vege	15%
mix ocean-vege-sand	11%
mix ocean-sand	9%
pure ocean	8%
mix vege-sand	6%
pure vege	6%
mix snow-ocean-vege	5%
...	...
pure snow	2%

The figure (1) shows the distribution of the $\{c_i\}$ values in the 2 main axis obtained by principal components analysis. On this figure the surface are classified according to the maximum value in $\{c_i\}$.

Surface skin temperature (thermal only)

The surface skin temperature T_b is the main parameter in the thermal region. This temperature is given as additional data in the TIGR-3 data base of atmospheric profiles (see [1]). Unfortunately, in the TIGR-3 data base, the surface temperature is always equal to the temperature at the lower atmospheric level (the surface skin temperature seems not be measured).

$$T_b = T(39) + \Delta T$$

where ΔT is a random number distributed as explained hereafter.

An "illumination flag" is first activated or not randomly with a probability of 40%. Then, according to this flag, the ΔT is set randomly with uniform distribution within the ranges:

$$\Delta T = [-15.0, +15.0]. \quad \text{illumination flag not set}$$
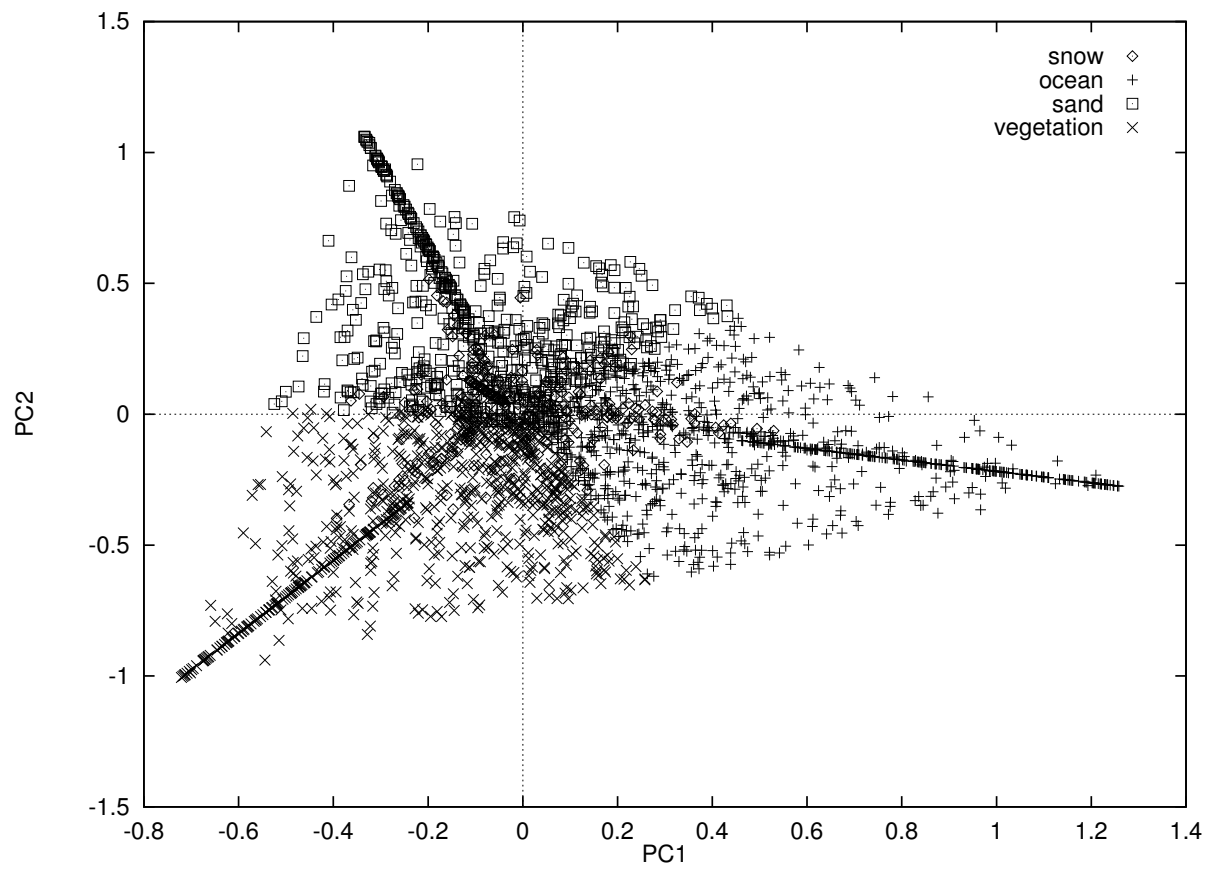$$\Delta T = [0.0, +50.0]. \quad \text{illumination flag set}$$

Figure 1: Distribution of the surface weighting factors $\{c_i\}$ projected on PC1 and PC2 (main components obtained by principal components analysis).

Surface emissivity (thermal only)

The surface emissivity ϵ is supposed to be not dependent on the wavelength λ and is a random number with uniform distribution in the range:

$$\epsilon \in [0.85, 1]$$

In practice, as input for SBDART, it is the albedo $(= 1 - \epsilon)$ that is set.

Atmospheric profile

The atmospheric profile is extracted from the TIGR-3 data base (see [1]). A random permutation of the profiles is performed.

Cloud cover

Program

The cloud cover is generated by the program `makecloud.c`. This program generates the file cloud.txt that contains the characteristics of the cloud cover for 3000 different realizations.

Cloud layers

According to the ISCCP cloud classification [4], 3 layers are used: low level clouds, middle level clouds and high level clouds. The total cloud cover used as input for the radiative transfer computation is simply the sum of these 3 cloud layers. The characteristics of each layer is totally independent on the others layers.

The table hereafter gives, for each layer, the cloud top pressure from ISCCP classification, the height range in kilometer, the probability P of this cloud layer and the probability P_{ice} that the cloud phase is ice[1].

layer	top pressure	height	prob. P	P_{ice}
low	$>680\ mb$	$[0.5, 3.5]\ km$	50%	0%
mid	680-440 mb	$[4.0, 7.0]\ km$	40%	25%
high	$<440\ mb$	$[7.0, 16.0]\ km$	30%	100%

First, the program generates a 3-values flag (e.g. 011, 101, ...) using the probabilities P that the levels are cloudy and the phase probabilities .

---

[1]The probability that the cloud phase is water droplet is simply $P_{water} = 1 - P_{ice}$.

Cloud layer phase

For the cloudy layers, the phase is chosen randomly using the probability P_{ice} given in the table. For the ice phase layers, the flag value is change from 1 to 2 (e.g. 012, 102, ...).

Cloud layer height

For each cloudy layer, the layer height is chosen randomly and with uniform probability in the range of the table given before.

Cloud layer droplets size

For the water phase layers, two kinds of clouds are defined: precipitating and non-precipitating cloud. This kind is choose randomly and with and equal probabilities. Then, the drop effective radius is chosen randomly in the range given in the table:

kind	nre
non-precipitating	$nre = [2, 25]\,\mu m$
precipitating	$nre = [25, 128]\,\mu m$

For the ice phase layers, the single scattering co-albedo $(1 - a)$[2], predicted using the Mie theory, is modified by a factor chosen randomly in the range $[0.5, 1.0]$ (see [3]):

$$(1 - a) \,=\, nre\,(1 - a)$$

Cloud layer optical thickness

According to ISCCP classification, cloud layers are classified into 3 classes of optical depth: thin, mid and thick. For each cloudy layer, this class is chosen randomly and with equal probabilities P_{type}. Then, the optical thickness τ[3] of the layer is chosen randomly in the τ ranges given in the table hereafter:

type	P_{type}	τ range
thin	$\frac{1}{3}$	$[0, 3.6]$
mid	$\frac{1}{3}$	$[3.6, 23]$
thick	$\frac{1}{3}$	$[23, 379]$

---

[2]the single scattering co-albedo $(1 - a)$ is the ratio between the probability of absorption and the probability of scattering.

[3]The optical thickness τ specifies the cloud optical depth at a wavelength of $\lambda = 0.55\mu$. Internal tables are used to estimate optical depth at other wavelengths (see [3]).

Summary - Upper layer

For the cloudy atmosphere, the probabilities for the upper layer are (independently of the underneath layers):

ISCCP	low	mid	height
thin	9%	12%	12.3%
mid	9%	12%	12.3%
thick	9%	12%	12.3%

The probability of thin cirrus over land (that means without underneath cloud layer) is only 3.7%.

Aerosols

In the simulation, none stratospheric aerosol layers are used. For the boundary layer aerosol, the internal wavelength dependences are used. The type of aerosol is chose randomly and with equal probability within:

type	$P_{aerosol}$
none	20%
rural	20%
urban	20%
oceanic	20%
tropospheric	20%

3   Creation of the Data Set

Random Generation of the SBDART Input

This is done using the program `makeheader.c`. This program does not run SBDART but creates a set of header file that contain all the needed information to run the radiative transfer model. The following command generates 2310 header files in the specified directory with the prefix 'sunny':

```
makeheader 2310 /gerbdata/nic/RadiaCurves/Sunny/sunny
```

Note that to run the makeheader program, the output of makesurface and makecloud programs must be present in the working directory.

Creating the SW and LW curves

For one given header file (i.e. sunny_header_0000), the SW and LW curves for clear and cloudy conditions are built using the program `run_sbdart.c` with the `-sw` and/or `-lw` options. The following command generates the spectral curves corresponding to one given header file:

```
run_sbdart  /gerbdata/nic/RadiaCurves/Sunny/sunny_header_0197 -
sw -lw
```

The spectral curves are generated in the same directory as the header file. Note that the following programs are needed in the working directory:

```
file_sel   (available in the BATS library)
conv_out5  (to process SBDART 5th output format)
```

Generated data

The radiative transfer computing have been performed for 2310 different Earth-atmosphere conditions. For each of these Earth-atmosphere realization, 6 files are generated:

file name	content
sunny_header_%04d	ASCII file with the input conditions
sunny_sw_cs_%04d	solar spectral flux curves without cloud layer
sunny_sw_cl_%04d	solar spectral flux curves with the cloud layer
sunny_lw_cs_%04d	thermal spectral radiances curves without cloud layer
sunny_lw_cl_%04d	thermal spectral radiances curves with the cloud layer
atms_%04d	atmospheric profile

These curves are stored with in the directory:

```
/gerbdata/nic/RadiaCurves/Sunny
```

Solar curves content

Each `*_sw_*` file contains the spectral **flux** $F_{\theta_s}(\lambda)$ in $Wm^{-2}\mu m^{-1}$ according to the wavelength $\lambda\,[\mu m]$ and for the following set of solar zenith angle

$$\theta_s = \{0, 10, 20, 30, 40, 50, 60, 70, 80\}^o$$

The spectral flux curve for solar reflected radiation is built between $\lambda = 0.25\,\mu m$ and $\lambda = 4.0\,\mu m$ using wavelength increment $\Delta\lambda = 0.005\,\mu m$:

λ	$\Delta\lambda$
$[0.25, 4.0]\,\mu m$	$0.005\,\mu m$

For each header file, the `run_sbdart` program generates 2*9 files **curve_sw_cs_%04d_X** and **curve_sw_cs_%04d_X** with X=0,10, ..., 80. The program `layout_sw` performs the merging of these files and creates the files **curve_sw_cs_%04d** and **curve_sw_cs_%04d**.

Thermal curves Content

Each `*_lw_*` file contains the spectral **radiance** $F_{\theta_v}(\lambda)$ in $Wm^{-2}\mu m^{-1}sr^{-1}$ according to the wavelength $\lambda\,[\mu m]$ and for the following set of viewing zenith angle:

$$\theta_v = \{0, 5, 10, 15, 20, 25, ..., 70, 75, 80, 85\}^o$$

The spectral radiance curve for thermally emitted radiation is built between $\lambda = 2.5\mu m$ and $\lambda = 100.0\mu m$ using wavelength increment $\Delta\lambda$:

λ	$\Delta\lambda$
$[2.5, 20.0]\,\mu m$	$0.05\,\mu m$
$[20.0, 100.0]\,\mu m$	$1\,\mu m$

4 Utility programs

Layout the solar curves

The program `layout_sw.c` must be used to merge the solar reflected files generated by SBDART (1 file per solar zenith angle) into a single file. The code must be updated before use because the data paths are hard-coded in the program.

Test curves integrity

The program `test_curve` can be used to check the integrity of the spectral radiance/flux curves generated by SBDART. This program detects the SBDART failures. The following problems have been detected:

- Some thermal radiances curves does not provide values at $\lambda > 80\mu m$. So, there are missing data in the range $80 < \lambda < 100\,\mu m$. This problem has been detected for 88 curves (44 pairs clear/cloudy) in the data base.

Curves visualization

There is a gnuplot script (`script.gnu`) that can be used to generate graphs of $L_{sw}(\lambda)$ and $L_{lw}(\lambda)$. The program `view_curve` can also be used to visualize the spectral curves in the data base. Typical command is:

```
view_curve /gerbdata/nic/RadiaCurves/Sunny/sunny 2310
```

Curves surface type classification

The program `surf_classif` can be used to classify the different elements in the data base according to the main constituent of the surface: snow or ocean or vegetation or sand. The result of the classification is stored in the file `surf_class_v3.txt`. The table hereafter summarizes this classification.

type	# elements	frequency
SNOW	318	13.8 %
OCEAN	761	32.9 %
VEGE	676	29.3 %
SAND	555	24.0 %

Curves cloud cover classification

The program `cloud_classif` can be used to classify the different elements in the data base according to the kind of cloud cover. Note that the classification is based only on the higher cloudy layer. The classification used is the one of the ISCCP. The following code is used:

code	layer height	optical thickness
0	clear sky	clear sky
1	low level ($p > 680\,mb$)	thin ($\tau < 3.6$)
2	low level ($p > 680\,mb$)	mid ($3.6 < \tau < 23$)
3	low level ($p > 680\,mb$)	thick ($23 < \tau$)
4	mid level ($400 < p < 680\,mb$)	thin ($\tau < 3.6$)
5	mid level ($400 < p < 680\,mb$)	mid ($3.6 < \tau < 23$)
6	mid level ($400 < p < 680\,mb$)	thick ($23 < \tau$)
7	height level ($400\,mb > p$)	thin ($\tau < 3.6$)
8	height level ($400\,mb > p$)	mid ($3.6 < \tau < 23$)
9	height level ($400\,mb > p$)	thick ($23 < \tau$)

The result of the classification is stored in the file `cloud_class_v3.txt`.

5   Convolution with spectral response filters

Introduction

The data base of spectral radiance fields is convoluted with a set of spectral response curves corresponding to the channels of different instruments. This provides, for each curve $L_i(\lambda)$ in the data base, the filtered radiances $L_{i,ch}$:

$$L_{i,ch} \;=\; \int_0^\infty L_i(\lambda)\phi_{ch}(\lambda)d\lambda$$

The unfiltered radiances are obtained using the broadband filter ("bb.fil") characterized by the flat spectral response $\phi(\lambda) = 1$.

Program

The convolution is done by the program `create_nb_rad_db` (LNIC library) that takes 2 arguments: the listing of the spectral radiance curves to be convoluted and the listing of the filter (`list_filter.txt`) to be applied. A batch file (`batch.bat`) creates the listing of the curves and calls the convolution program.

Listing of the filter

The convolution is currently done for the different channels of the GERB, CERES (PFM), Meteosat-7, Meteosat-5 and SEVIRI-1 instruments as listed in the table hereafter.

column id	filters	name
0	$\phi(\lambda) = 1$	broadband.txt
1	GERB TOT	gerb2_mean_tot.txt
2	GERB LW	gerb2_mean_lw.txt
3	GERB SW	gerb2_mean_sw.txt
4	MS7 visible	ms7_S1.txt
5	MS7 water vapor	ms7_T1.txt
6	MS7 infrared	ms7_T2.txt
7	HRV	seviri_S0.txt
8	$0.6\,\mu$	seviri_S1.txt
9	$0.8\,\mu$	seviri_S2.txt
10	$1.6\,\mu$	seviri_S3.txt
11	$3.9\,\mu$	seviri_T0.txt
12	$6.2\,\mu$	seviri_T1.txt
13	$7.3\,\mu$	seviri_T2.txt
14	$8.7\,\mu$	seviri_T3.txt
15	$9.7\,\mu$	seviri_T4.txt
16	$10.8\,\mu$	seviri_T5.txt
17	$12\,\mu$	seviri_T6.txt
18	$13.4\,\mu$	seviri_T7.txt
19	MS5 visible	ms5_S1.txt
20	MS5 water vapor	ms5_T1.txt
21	MS5 infrared	ms5_T2.txt
22	CERES TOT	ceres_tot.txt
23	CERES LW	ceres_lw.txt
24	CERES SW	ceres_sw.txt
25	#	#
26	curve name	curve name

Notes:

- The visible filters of MS7 (column 4) and MS8 (column 7) are provided by Yves Govaerts (EUMETSAT) and are defined over an extended wavelength range [0.3:1.3] μm

- The visible filter of MS5 (column 19) is the one provided on the EUMETSAT web site. According to Yves Govaerts [2] this spectral response should not be used and the spectral response curve of MS7 VIS should be used instead.

Generated data base of filtered radiances

The filtered radiances are stored in various ASCII files:

```
db_sol_XX.txt
db_th_XX.txt
db_th_flux.txt
```

where XX is the solar zenith angle $\theta_s = \{0, 10, ..., 80\}$ (solar) or the viewing zenith angle $\theta_v = \{0, 5, 10, 15, ..., 80, 85\}$ (thermal). The file db_th_flux.txt contains the thermal flux. In these files, each line correspond to a different Earth-atmosphere condition and each column to a different spectral response curve.

6 Comparison with observed NB SEVIRI radiances

Data and Calibration

For this comparison the SEVIRI slot 200309021230 has been used. The calibration for this slot is given in the prologue file (see values hereafter). The 0.6, 0.8, 1.6 and HRV calibration have been replaced by values provided by Yves Govaerts (personal communication):

```
channel                        gain   space
0.6 : 0.022900 -1.167900  : 0.041784 51.0
0.8 : 0.030200 -1.540200  : 0.026458 51.0
1.6 : 0.023900 -1.218900  : 0.011264 51.0
3.9 : 0.003743 -0.190880  : 0.001368 51.0
6.2 : 0.046410 -2.366927  : 0.009958 51.0
7.3 : 0.081972 -4.180563  : 0.007265 51.0
8.7 : 0.125621 -6.406651  : 0.005729 51.0
9.7 : 0.152328 -7.768709  : 0.004056 51.0
10.8: 0.195937 -9.992782  : 0.016456 51.0
12.0: 0.214595 -10.944323 : 0.014128 51.0
13.4: 0.209168 -10.667561 : 0.014738 51.0
HRV : 0.031600 -1.611600  : 0.282257 51.0
```

where the gain is given in $[Wm^{-2}sr^{-1}NC^{-1}]$. For the solar channels comparison, only SEVIRI data with SZA between 40 and 60 degrees have been used.

VISIBLE 0.6 - VIS 0.8
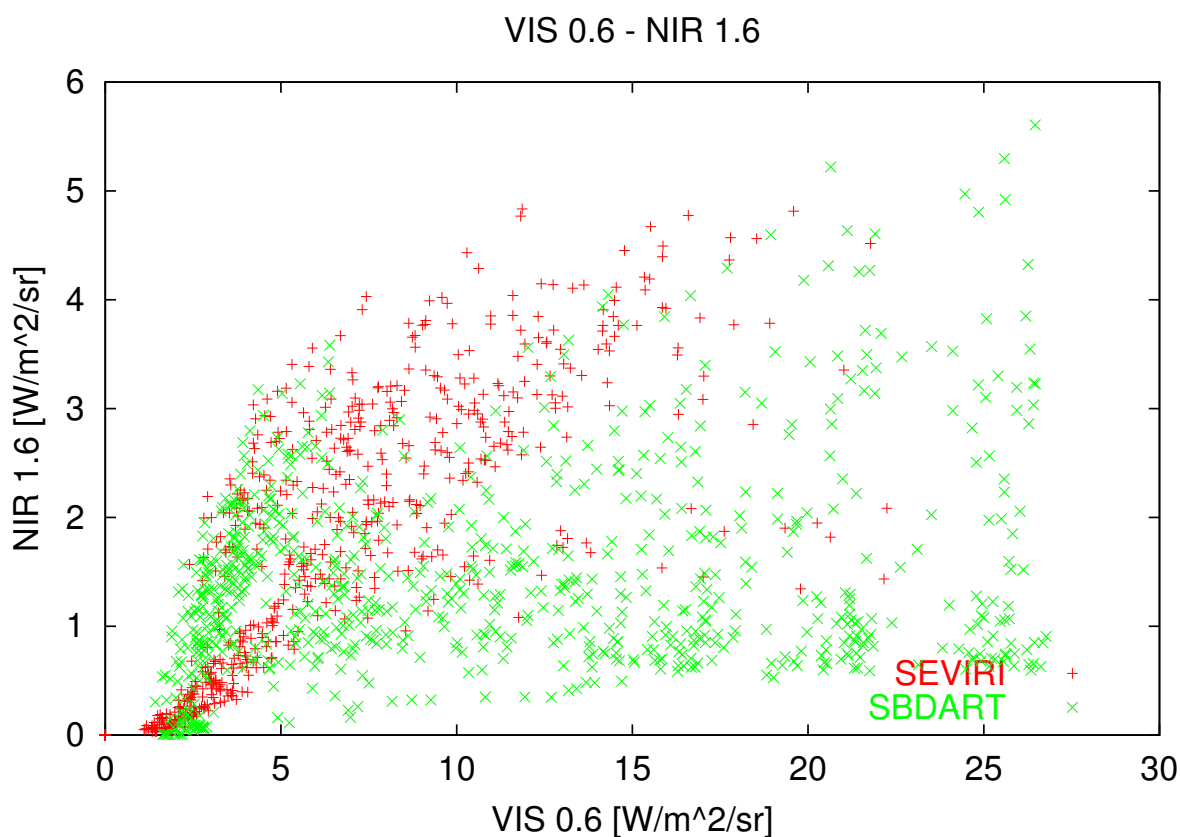
Scatter plot

VIS 0.6 - VIS 0.8
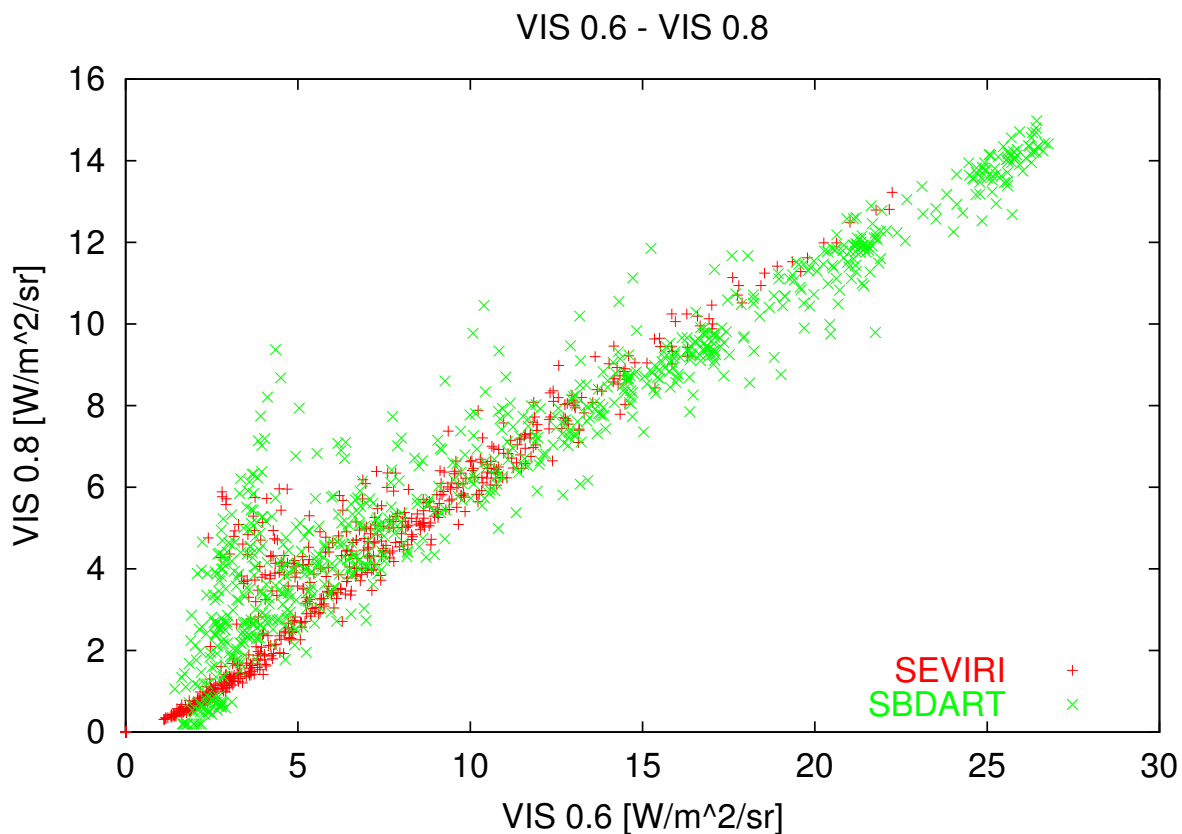
Comments

- In the database there is data with 0.6 radiance between 24 and 28 which are not observed by SEVIRI. This probably corresponds to RTM over snow covered surface (TBC).

# VISIBLE 0.6 - NIR 1.6

Scatter plot

VIS 0.6 - NIR 1.6

Comments

- Here also there is simulated points between 24 and 28 VIS 0.6 radiances that are not observed by SEVIRI. For these points the NIR 1.6 value shows significant change. There is probably also optically thick water cloud.

- There is a lot of simulated point with very low NIR 1.6 that are not observed. This correspond probably to optical thin ice clouds not observed.

- There is observed points with VIS 0.6=10 and NIR 1.6=4 that are observed and not simulated.

WATER VAPOUR : 6.2 - 7.3

Scatter plot
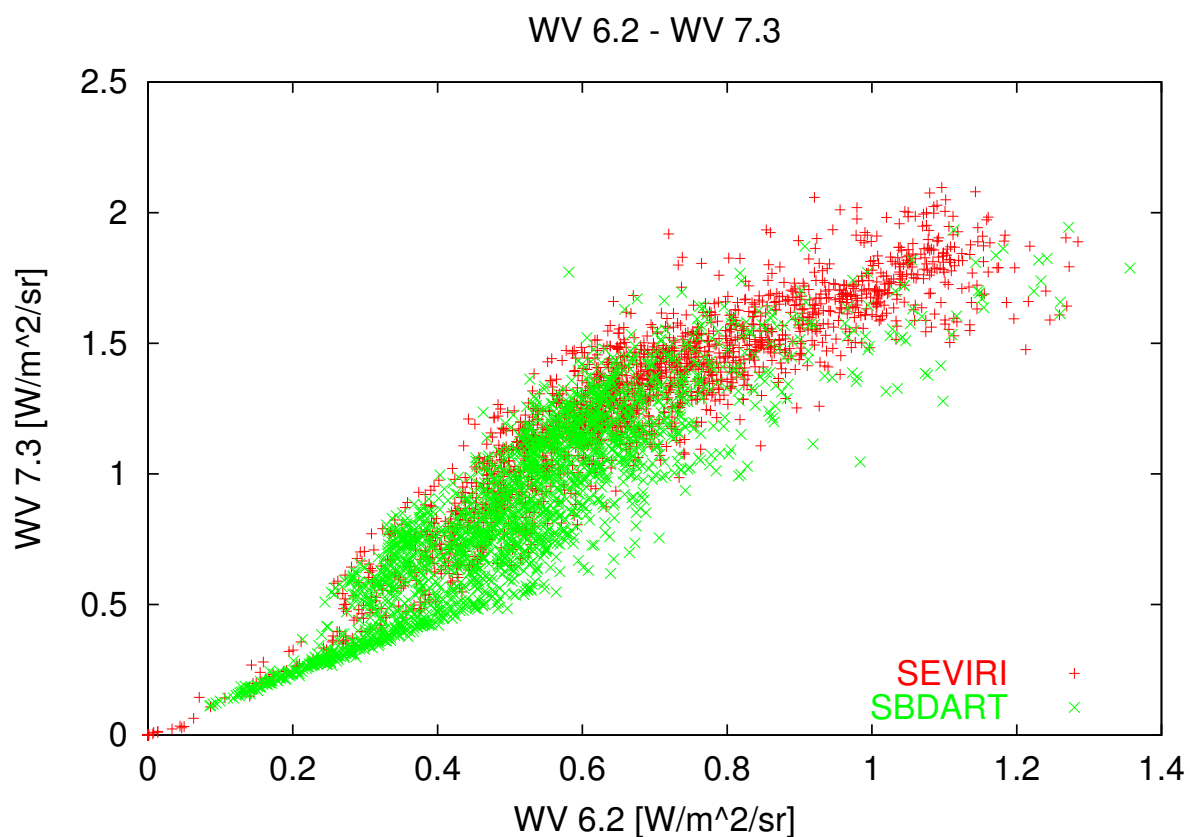
Comments

- Scene with dry atmosphere and hot surface are often observed by SEVIRI but seldom represented in our data base.

INFRARED : IR 8.7 - IR 9.7

Scatter plot

IR 8.7 - IR 9.7
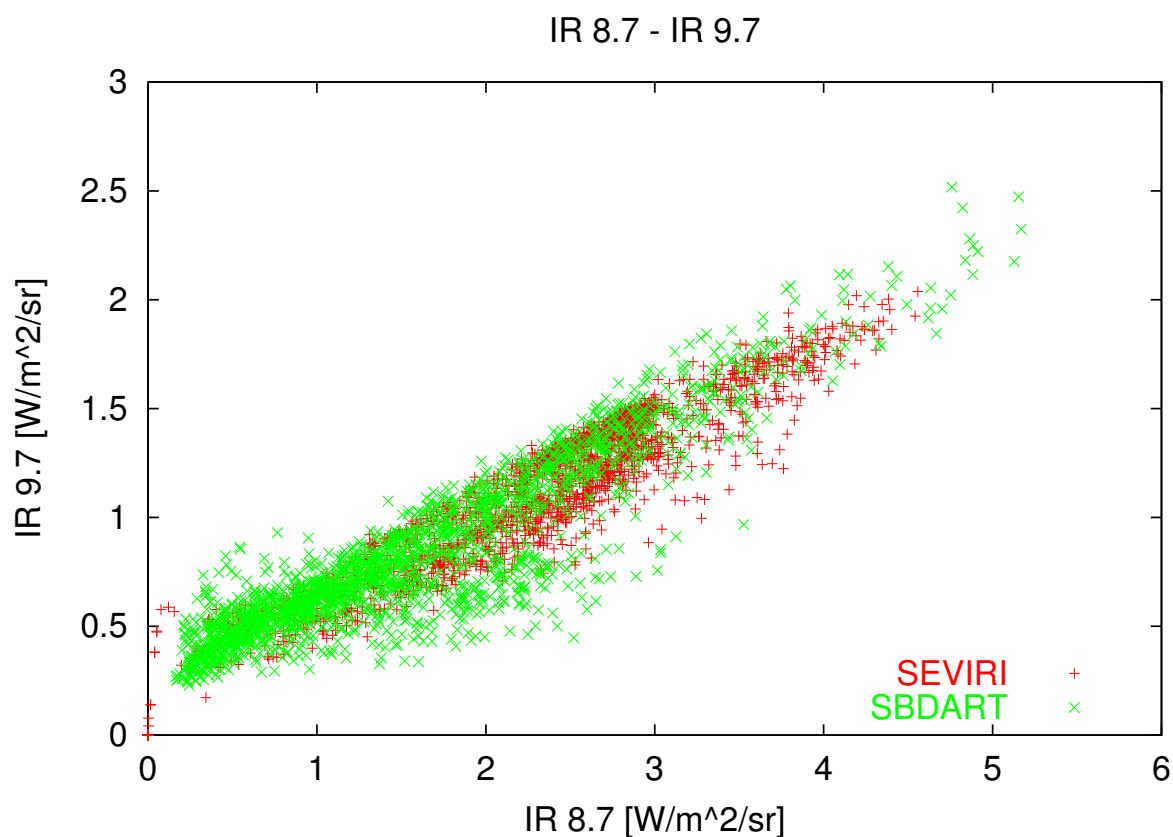
Comment

- The observed IR 8.7 radiance is limited to 4.5 while in the data base there exist higher radiance. This is probably due to the weak emissivity of the desert in the IR 8.7 channel (TBC).

- In the data base there is a cluster of point with lower IR 9.7 radiance (for IR 8.7 of about 2) which is not observed by the instrument.

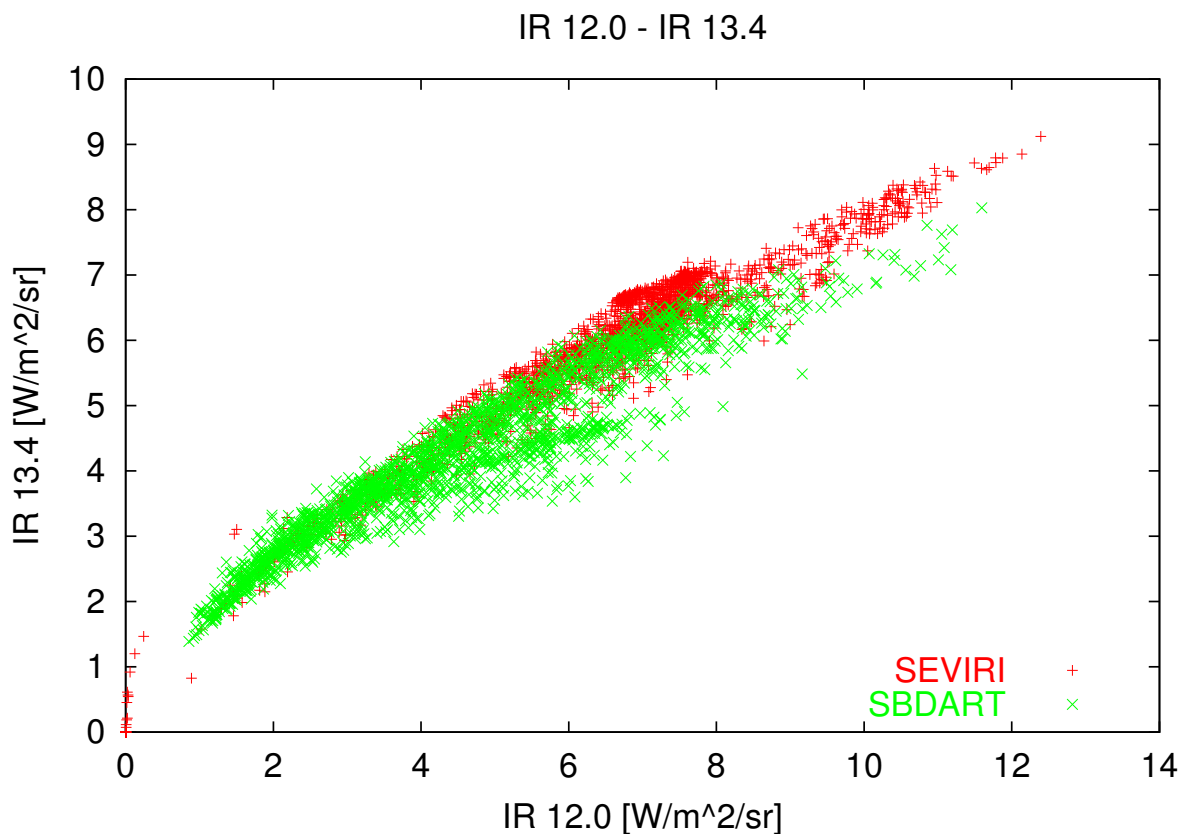# INFRARED: IR 10.8 - IR 12.0

Scatter plot
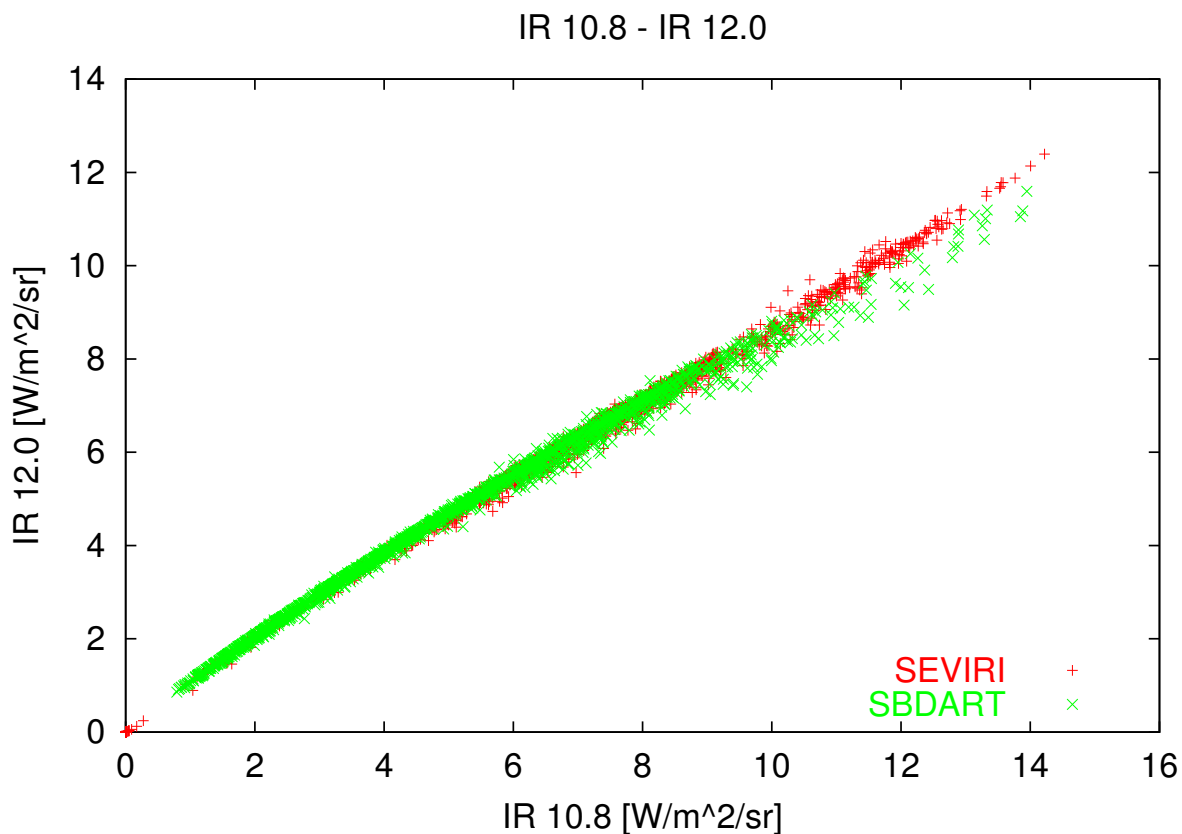
Comments

- Seems OK except for hot surface with 10.8 radiance higher than 10 for which the ratio of IR 10.8 and IR 12 is different between observation and simulation. This can be due to a smaller emissivity at 10.8 than at 12 for desert surface (TBC).

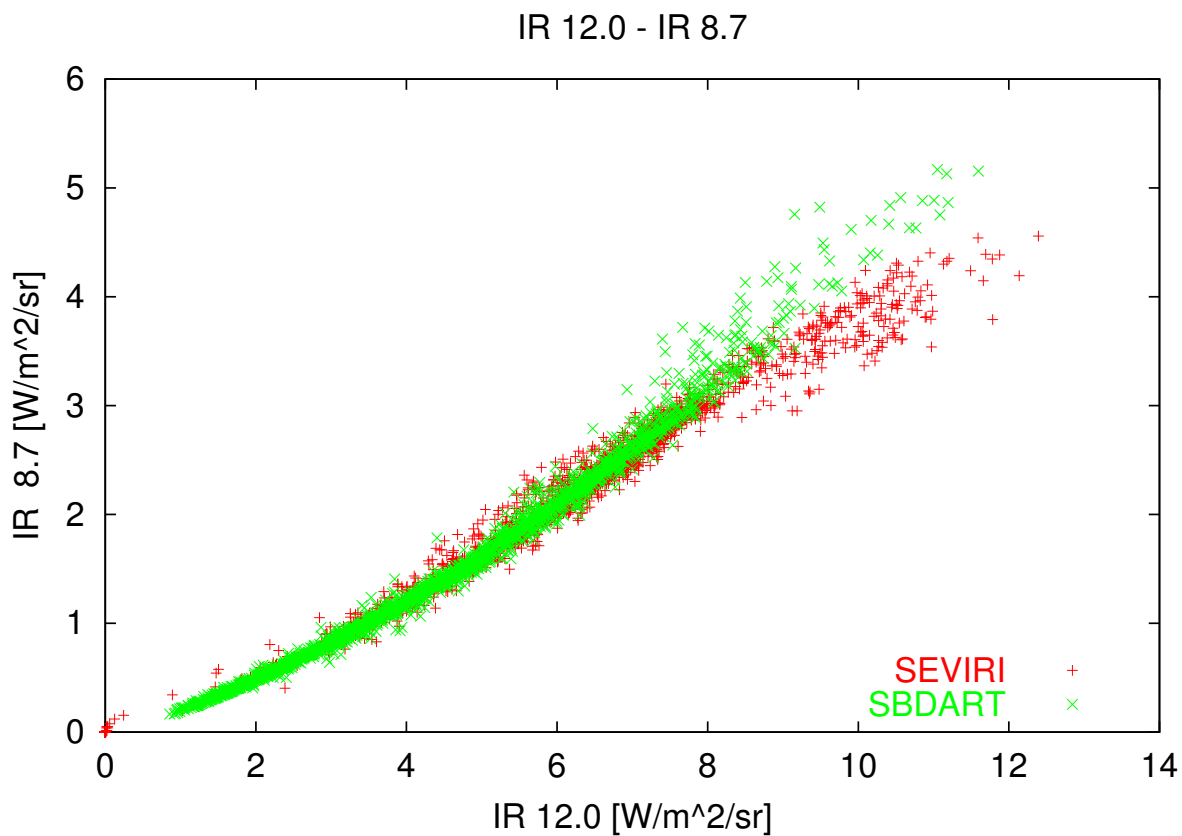# INFRARED : IR 12.0 - IR 13.4

Scatter plot

Comments

- In general the observed CO2 radiance is higher than the simulations, specially for medium and hot scenes. For cold clouds this seems to be OK.

INFRARED : IR 12.0 - IR 8.7

Scatter plot

IR 12.0 - IR 8.7

Comments

- The effect of low emissivity of desert surface is well visible on this scatter plot.

References

[1] N. Clerbaux. Use of TIGR-3 atmospheric profiles as input for SBDART. Technical Note MSG-RMIB-GE-TN-0029, RMIB, December 1999.

[2] Y. Govaerts. Correction of the meteosat-5 and -6 radiometer solar channel spectral response with the meteosat-7 sensor spectral characteristics. *International Journal for Remote Sensing*, 20(18):3677–3682, 1999.

[3] P. Ricchiazzi, S. Yang, C. Gautier, and D. Sowle. SBDART: A research and teaching software tool for plane-parallel radiative transfer in the earth's atmosphere. *Bulletin of the American Meteorological Society*, 79(10):2101–2114, 1998. available at http://arm.mrcsb.com/sbdart.

[4] WMO. Documentation of new cloud datasets. Document Version 1, International Satellite Cloud Climatology Project, 1996.