Frequency grid setups for microwave radiometers AMSU-A and AMSU-B

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The purpose of this text is to introduce the new variable "met_mm_accuracy" in the Atmospheric Radiative Transfer Simulator (ARTS) that is developed as a switch to select the size of the frequency grid for simulating a satellite channel, which can significantly reduce the calculation time. Now this variable is available only in sensor characteristics of two sensors - AMSU-A and AMSU-B. Variable "met_mm_accuracy" can be set to values between 0-3. The default value for "met_mm_accuracy" is 1, that means that maximum deviation from reference calculations is less than 0.1 K. The size of frequency grid is different for different satellite channels. The meaning of the other setting is explained at the end of this text.

The Advanced Microwave Unit (AMSU) is a microwave radiometer system. It consist of two separate units - AMSU-A and AMSU-B. More detailed information about these radiometers can be found in the NOAA KLM User Guide [1]. These radiometers are used for getting information about temperature and humidity vertical profiles, for weather prediction models and for other applications. These radiometers are flying on the operational meteorological satellites since 1998.

We use two sets of atmospheric states profiles to obtain sufficient statistics. We made a validation to show that proposed setup can be used in almost any atmospheric conditions. We use diverse set of atmospheric profiles, sampled from ECMWF forecasts [2], and set of atmospheric profiles sampled for radiative transfer model intercomparison campaign [3]. We will refer to the former as Chevallier dataset and latter as Garand dataset. The Chevallier dataset has 5000 atmospheric profiles sampled for maximizing the humidity variance and the Garand dataset has 42 diverse atmospheric profiles.

ARTS performs simulations for the monochromatic pencil-beam (MPBS) intensity. Monochromatic intensity I_ν is defined as the energy in a given direction per time per frequency per solid angle per area: $I_\lambda = \frac{dE_\nu}{dt \cdot d\nu \cdot d\Omega \cdot dA}$, $[W\, m^{-2}\, Hz^{-1}\, sr^{-1}]$. For microwave radiation the quantity of brightness temperature is often used to specify the radiation intensity. These two quantities are connected by:

$$T_B = \frac{h\nu}{k} \frac{1}{ln\left(1 + \frac{2h\nu^3}{I_\nu c^2}\right)},$$

where h is the Planck constant, k is the Boltzmann constant, c is the speed of light.

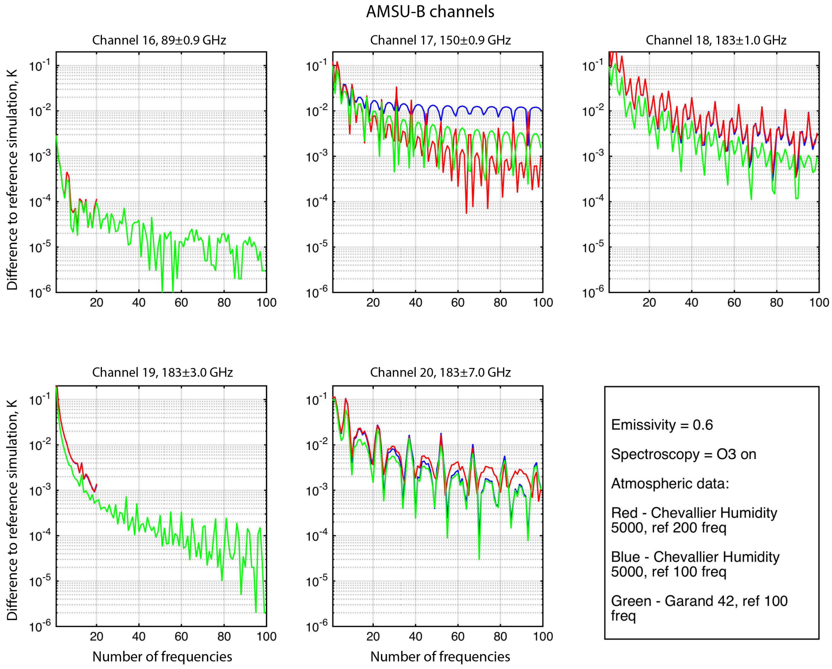

Figure 1: Maximum difference to the reference simulation for 100 sets of frequency grids for AMSU-B channels. The X-axis shows number of frequencies of the frequency grid

The simulated monochromatic intensities are converted to brightness temperatures. The mean over all simulated brightness temperatures within the frequency range of the channel represents the simulated brightness temperature of this channel. By increasing the number of frequencies per simulated channel we reproduce the radiation of that channel more accurately, but we need more time for making calculations. Based on the number of frequencies then satellite channel is divided into bins, the intensity is calculated at the center frequency. Hence the positions of frequencies are located at equal distances inside the satellite channel. Note, that by changing the number of frequencies we change the absolute position of the sampling frequencies inside the channel.

To reduce the calculation time Buehler et al.[4] has proposed technique of frequency selection and giving the different weight to frequencies for the High-resolution Infrared Radiation Sounder (HIRS) infrared radiometer. Later Holl et al.[5] showed that this technique is valid also for radiative transfer calculations with aerosols scattering. Eriksson et al.[6] summarize such work under term data reduction. The following work fits the definition of simple grid optimization.

In microwave region the spectral complexity is an order of magnitude lower than in infrared region. 200 frequencies inside the satellite channel should be more than enough to catch all of spectral properties of the channel. Thus, we can simulate brightness temperatures for all possible frequency grids with number of frequencies lower than 200. Then comparing them with reference brightness temperature we can quantitatively estimate which frequency grids give better result.

We use the mean brightness temperature of 200 frequencies within the channel as the

Table 1: Number of frequencies for different AMSU-B channels necessary to reach $E_s < 0,001\,K$ for different values of ground emissivities.

Emissivity	AMSU-B ch16	AMSU-B ch17	AMSU-B ch18	AMSU-B ch19	AMSU-B ch20
0.6	2	23	67	19	25
0.8	2	23	31	12	25
1.0	1	16	24	12	10

reference. We tested 100 frequency grids, the first has one frequency within the channel, each following grid has one more frequency. We calculate the error of simulation (E_s) for every frequency grid, according to the formula:

$$E_{s\,i} = max\,(\mid T_{b\,200,j} - T_{b\,i,j} \mid)\,,$$

$$i\,\epsilon\,[1,\ 100]; \qquad j\,\epsilon\,[1,\ 5000],$$

where T_b is the brightness temperature of specific channel sampled with i frequencies, i is the number of frequencies, j is the index number of atmospheric profile in dataset. Thus among all atmospheric profiles for a given number of frequencies i, $E_{s\,i}$ is absolute of maximum difference from reference.

The discussion below focuses on the AMSU-B radiometer, but can also be applied to AMSU-A radiometer. Figure 1 shows 5 plots for the 5 channels of AMSU-B channels. The plots show the relationship between error of simulation E_s (on the Y axis) and the number of frequencies (on the X axis). The relationship is inverse, decrease in the error of simulation when the number of frequencies is increasing. The decrease is not smooth and not constant, but uneven. This is due to the presence of narrow O_3 absorption lines inside the satellite channel. John et al.[7] showed that we can not neglect these lines in very dry atmospheric profiles. Recall that changing the number of frequencies we change their absolute position. Hence some frequency grids do not represent accurately enough absorption by O_3 lines.

We considered the two sets of atmospheric profiles separately. Errors of simulations for these two datasets mostly have the same pattern. The Garand dataset almost for all cases has a lower value. This is related to the fact that the Chevallier dataset has more extreme atmospheric profiles. A noticeable exception is channel 17 of AMSU-B, where the error of simulation for Garand dataset has a higher value. I think that the difference can be due to weak O_3 line inside this channel.

To check if the surface emissivity will influence the error of simulation, we estimated the number of frequencies to reach $E_s < 0,001\,K$. Table 1 shows these numbers for AMSU-B channels. It has an influence, although not strong. Only for the channel 18 the decrease is by a factor of 2.

For every satellite channel we select 4 configurations of frequency grids. These configurations can be selected by setting the variable "met_mm_accuracy" value between 0 and 3. The first configuration selects 1 frequency in the middle of every channel. The second, third and fourth configuration select different numbers of frequencies for every channel. This number was chosen, so the maximum difference to reference simulation is less than a certain threshold - 0,1 0,01 and 0,001 K respectively. Tables 2 and 3 show the maximum differences from reference for all satellite channels with 1 frequency per

Table 2: Error of simulation (E_s) for 1 frequency per channel for AMSU-A. This corresponds to “met_mm_accuracy=0”

Channel	Error of simulation, K
16	0.003
17	0.121
18	0.415
19	0.357
20	0.112

Table 3: Error of simulation (E_s) for 1 frequency per channel for AMSU-B. This corresponds to “met_mm_accuracy=0”

Channel	Error of simulation, K
1	0.004
2	0.001
3	0.004
4	0.363
5	0.370
6	1.852
7	2.202
8	1.306
9	1.116
10	0.625
11	0.646
12	0.674
13	0.958
14	0.317
15	0.002

channel. Tables 4 and 5 show the number of frequencies in the frequency grid that makes maximum difference less than 0,1 0,01 and 0,001 K respectively.

References

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Table 4: Number of frequencies to have Error of simulation (E_s) less than thresholds 0,1 0,01 and 0,001 K for AMSU-A (right) channels. Errors 0,1 K 0,01K and 0,001 K corresponds to "met_mm_accuracy=1", "met_mm_accuracy=2" and "met_mm_accuracy=3" respectively

Channels	Met_mm_accuracy				
	1		2		3
1	1		1		6
2	1		1		1
3	1		1		3
4	3		8		23
5	3		8		24
6	5		16		44
7	5		15		43
8	4		11		34
9	4		13		38
10	3		9		26
11	3		9		26
12	3		9		27
13	4		11		31
14	2		6		17
15	1		1		4

Table 5: Number of frequencies to have Error of simulation (E_s) less than thresholds 0,1 0,01 and 0,001 K for AMSU-B (right) channels. Errors 0,1 K 0,01K and 0,001 K corresponds to "met_mm_accuracy=1", "met_mm_accuracy=2" and "met_mm_accuracy=3" respectively

Channels	Met_mm_accuracy				
	1		2		3
16	1		1		2
17	2		18		23
18	2		20		67
19	2		7		19
20	3		10		25

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