FLISS: A USER-FRIENDLY SATELLITE SIGNAL SIMULATOR USING MONTE-CARLO AND LINE-BY-LINE TECHNIQUES FOR MULTIPLE SCATTERING LAYERED ATMOSPHERES

B.A. Fomin[1,2], M.P. Correa[2], J.C. Ceballos[2], R.A. Souza[2] and L.A. Machado[2]

[1]Russian Research Center “Kurchatov Institute”,1 Kurchatov sq., 123182 Moscow, Russia
[2]Satellite and Environmental System Division, CPTEC/INPE, Rod. Dutra, km 40,Cachoeira Paulista, SP, 12.630-000, Brazil

ABSTRACT

FLISS (Fast LIne-by-line satellite Signal Simulator) is a universal research and teaching software that simulates signals from multichannel satellite sensors of any spectral resolution. All sort of crucial processes that affect thermal and solar radiation (from microwaves to ultraviolet), both in clear-sky and cloudy/aerosol plane-parallel atmospheres, are meticulously treated by FLISS by means of unique Line-by-Line and Monte-Carlo techniques. It is noteworthy that present version of FLISS can simulate ‘*ab initio*’ satellite signals generated by outgoing thermal radiation in scattering atmosphere for sensors with any type of spectral resolution: high, middle, or low (up to ~10^3 cm^{-1}). FORTRAN-90 standard has been used, writing FLISS code as a package of user-friendly, UNIX- and MS-Windows- compatible programs. It is designed for development and validation of satellite data processing systems as well as for assessment of atmospheric components impact on satellite signals, at the same time being a useful teaching tool.

1. INTRODUCTION

Development and validation of satellite sensors and, in particular, their data analysis require accurate Line-by-Line (LBL) forward models which can simulate satellite signals both in clear-sky and cloudy/aerosol atmospheres. This work presents such universal, user-friendly and Fast LIne-by-lline satellite Signal Simulator (FLISS) that can be applied to any microwave, infrared, visible and ultraviolet mono- and multichannel sensors. FLISS incorporates a quadruple of program packages for each of the four different types of forward models, specifying: 1- thermal radiation in the purely absorbing atmosphere (this part is similar to the model of *Fomin et al.* [2003]), 2- thermal radiation in the plane-parallel scattering atmosphere, 3- solar radiation in the purely absorbing atmosphere, 4- solar radiation in the plane-parallel scattering atmosphere. In all the said cases, particulate absorption can be exactly treated along with gaseous.

FLISS treats all the fundamental scattering/absorption atmospheric processes except for line mixing, non-LTE and polarization effects, which is to be considered in further versions. In FLISS is applied the author’s fast Line-By-Line (LBL) algorithm [*Fomin*, 1994], whose efficiency has been found the best by *Kuntz and Hofner* [1999] for accurate gas absorption calculations. The LBL technique is used here not only to increase the calculation accuracy but also to facilitate the FLISS application in various tasks without a need to parameterize gas absorption beforehand (e.g. by the k-distribution method), which invariably involves additional effort. For a universal but at the same time accurate account of scattering, Monte-Carlo method is used, which so far has been applied to the plane parallel atmosphere, but is projected to suit 3-D geometry as well. It must be emphasized that at present only FLISS, based on the recently developed algorithm by *Fomin* [2005], can accurately take into account cloud/aerosol scattering of thermal radiation not only in narrow but in any spectral bands (even up to ~1000 cm^{-1}). For treatment the solar radiation scattering we used the original Monte-Carlo technique described in detail by *Fomin and Mazin* [1998].

It must be emphasized that FLISS has been devised to be an utmost user-friendly model, whereas user does not need to enter any information devoid of a clear physical meaning. Accordingly, FLISS has been written in FORTRAN-90 standard in order to implement the array dynamic management methods and the mechanism of dynamic pointer operation support. This considerably facilitates FLISS operation for various observation geometries, in all atmospheric conditions and for any sensor's response functions; as well as using tables with real optical properties of clouds, aerosols and surface, due to a rather free format. Therefore, FLISS can be also recommended as a teaching model for under- and post-graduate students.
Besides it is of importance that the major part of the basic physical assumptions and algorithms applied in FLISS has been already implemented in:

- benchmark calculations for climate studies [*Fomin and Gershanov*, 1997]
- investigations of radiative transfer in cloudy and hazy atmosphere [*Fomin and Mazin*,1998]
- satellites measurement simulation (IASI, IMG, NPOESS *etc*.) [*Uspensky and Romanov*, 2003].

Moreover, those assumptions have been verified by means of code intercomparison ([*Ellingson and Wiscombe*, 1996], [*Halthore et al*., 2005], etc.).

2. PHYSICAL MODELS AND ALGORITHMS

For gas absorption calculations, we have used van Vleck-Weisskopf, sub-Lorentz and Voigt line-shape functions, HITRAN-11v [*Rothman et al.*, 2003] spectral database and the CKD-2.4 water vapor continuum model, along with the continuum models of O_3, O_2 and N_2 [*Mlawer et al.,*1999]. As aforesaid, to calculate thermal radiation in the purely absorbing atmosphere, thoroughly verified algorithms and physical models were applied, similar to those described in the work by *Fomin et al.* [2003]. Nevertheless, additional measures were taken to increase the calculation speed for multichannel sensors by means of program modernization. Detailed algorithms for longwave calculations with or without scattering one can find in the paper by *Fomin* [2005], whereas shortwave algorithms are covered in the paper by *Fomin and Mazin* [1998].
Special efforts have been applied to make FLISS as user-friendly as possible; an instruction manual is supplied in the "READ_ME.txt" file attached to the program package. It should be noted that user does not need to be concerned with the multitude of angular, spatial and wavenumber internal calculation grids applied in FLISS for solving the radiation transfer equations. But an advanced user can easily modify those grids following practical hints in the "READ_ME.txt". Such modifications may be useful, for example, to increase the calculation speed in certain tasks by using rougher grids, whenever high calculation accuracy is not paramount. Here it should be noted that the recommended universal grids have been chosen on the basis of the author's long experience in the radiation transfer calculations so that the calculation errors could be always negligible as compared to the errors related to uncertainties in initial spectroscopic information and optical models of clouds and aerosols. Being universal these grids sometimes may not be of maximum efficiency. Furthermore, user does not need to mind dimensions of the input arrays, e.g. number of levels in the atmospheric model (up to ~10^3 levels are available). Relevant internal arrays are allocated by the program in the computer memory after the FLISS start-up.
Thus, user is merely expected to enter his atmospheric and cloud/aerosol optical models (tables of scattering/absorptions indexes and Stokes parameters), which should be written in convenient and readable ASCII files of a rather free format and structure despite the fact that FLISS usually requires DIRECT ACCESS input files of a fixed format for effective calculations. To overcome this problem, on the start-up the program automatically copies new user's ASCII files to the internal FLISS library containing DIRECT ACCESS files. Consequently, for each calculation user has simply to point out the path to a file from his library in the FLISS control file. Besides it should be noted that during the package installation user has to copy spectroscopic information from ASCII to DIRECT ACCESS files with the help of a special program attached to FLISS (for detail see "READ_ME.txt").
For FLISS demonstration we chose an IASI type multichannel sensor (7840 channels from 640 to 2600 cm^{-1} with high spectral resolution of 0.25 cm^{-1}). Figure 1 shows simulated brightness temperatures (LOS= 60^{O}) for a clear-sky tropical atmosphere (8 atmospheric gases H_2O, CO_2, O_3, CH_4, CO, N_2O, O_2 and N_2 for 45 altitude levels from 0 up to 70 km). Moreover, we used a so-called "medium" water cloud (effective radius = 6.2 μm; the model borrowed from the paper by [*Fu et al.,* 1997]), which was positioned at 4.0 to 5.0 km (temperature at the cloud top = 277.0 K). Additionally, Figure 1 demonstrates calculations with such cloud, considering cloud drops absorption exclusively, whereas Figure 2 demonstrates differences in brightness temperatures with and without the cloud scattering (cloud optical thickness = 1.0). It is obvious from the figures that these differences are not negligible (up to ~4 K), which only corroborates the benefits of FLISS use.

It is worth noting that it only took ~5 minutes to make the calculation in Figure 1 and ~20 hours for longwave Monte-Carlo calculation (random errors ~0.1 K) shown in Figure 2 on an ordinary laptop (HP with Athlon-

2200MHz / RAM 512 MB / WindowsXP). For a similar work station under Linux it was ~5 times faster. The shortwave calculations, using rougher wavenumber grids and simpler mathematical equations, are usually faster. For instance, shortwave MODIS channel requires ~10 minutes of Monte-Carlo calculation in a cloudy atmosphere (with random errors ~0.1%) using the above laptop.

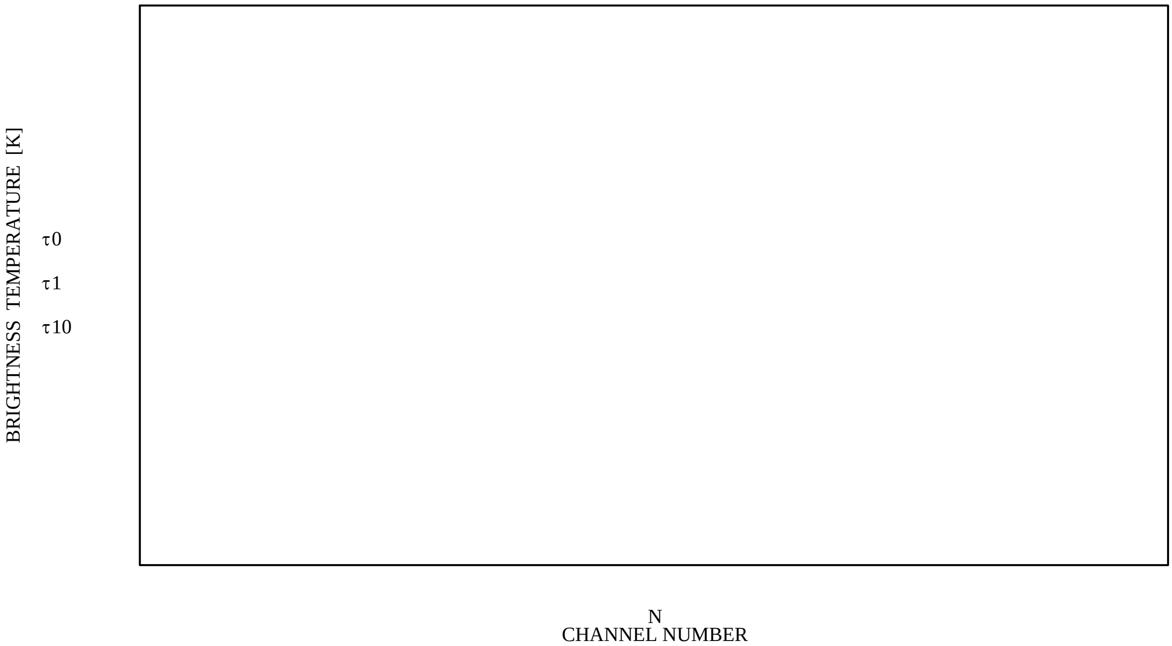

Figure 1. Brightness temperatures in the IASI channels (LOS= 60^O) for tropical atmosphere (8 atmospheric gases H_2O, CO_2, O_3, CH_4, CO, N_2O, O_2 and N_2 for 45 altitude levels from 0 up to 70 km).
Upper (red) line τ10- clear-sky atmosphere; middle (blue) τ1 and lower (pink) τ10- for cloud of optical thickness 1.0 and 10.0 (see in text).

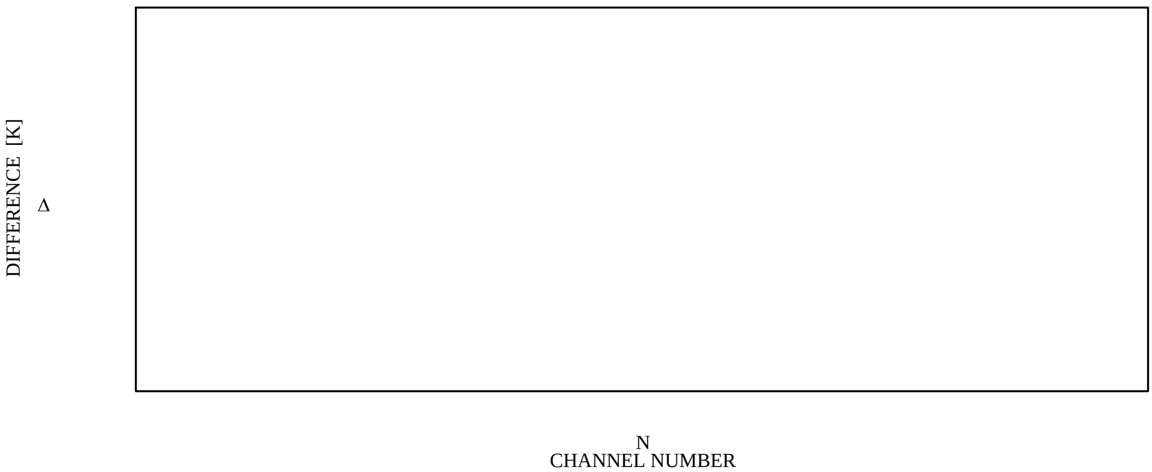

Figure 2. Difference Δ between the brightness temperature calculations with and without cloud scattering for the cloud of optical thickness 1.0. The same atmospheric conditions that for Figure 1.

3. SUMMARY

In this paper we have briefly described FLISS, a universal research and teaching software that simulates satellite signals generated by outgoing microwave, infrared, visible and ultraviolet radiation both in clear-sky and cloudy/aerosol plane parallel atmospheres. Despite meticulous Line-by-Line and Monte-Carlo codes used in FLISS, the latter is rather prompt (and is arguably the fastest in the array of similar codes). For example, the average computation time on an ordinary laptop for a single IASI type IR channel is only about 0.03s for calculations in a pure absorbing atmosphere, and ~10s for calculations in a cloudy atmosphere. The simulation of shortwave channels with moderate spectral resolution (such as MODIS) usually takes no more than ~10 minutes, even for cloudy atmospheric conditions. Thus, FLISS can be widely distributed in the geoscience community.

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