MATISSE
Advanced Earth Modeling for Imaging and Scene Simulation : first results

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ABSTRACT

In this paper we present MATISSE 1.1 a new background scene generator, whose goal is to compute spectral or integrated radiance images of natural background, as well as the transmission of a hot gas signature.
The spectral bandwidth for this version of the code is from 750 to 3300 cm^{-1} (3 to 13 µm) with a 5 cm^{-1} resolution. Gaseous absorption is computed by a Correlated K model. The spatial variability of atmospheric quantities (temperatures and mixing ratios, among others) is taken into account, using variable profiles along the line of sight.
Natural backgrounds include the atmospheric background, low altitude clouds and the Earth ground. The radiation models used are designed for observation at low spatial resolution of clouds and soils, so a texture model was developed to increase the high spatial resolution rendering in the metric range.
Intermediate outputs of the code deliver radiance and transmission restricted to a single line of sight, in which case atmospheric refraction effects are taken into account. Along this line of sight the transmission can also be computed using a line-by-line model, which is useful to propagate the radiation emitted by a hot gas source (fires, aircraft or missile plume).

MATISSE 1.1 was released in June 2002, so this paper is devoted to a presentation of the first results obtained with the code and some validation tests.

1. INTRODUCTION

MATISSE 1.1 (**M**odélisation **A**vancée de la **T**erre pour l'**I**magerie et la **S**imulation des **S**cènes et leur **E**nvironnement) is a new computer code devoted to the calculation of background radiance images. The development of the code, which began in April 2000, has been motivated by the need of target/ background contrast computation (in order to predict target detection performance of electro-optics sensors) and also by the lack of computer code able to quickly calculate scenes while retaining a fine physical description within the scene. Indeed, most of today's atmospheric radiation codes can only calculate radiance along one single line of sight, so an image containing N*M pixels is built by using N*M independent radiance calculations. Moreover in order to reduce time computation, these codes use band models for the radiation propagation and consequently do not take geographic variability of atmospheric properties into account. In addition, for contrast evaluation we need to compute target intensity. If the emission's target exhibits a hot gas signature, a line-by-line model or a specific narrow-band model has to be used. If the line-by-line model is chosen, the two calculations have to be matched for consistency, *i.e.*, background radiance has to be calculated and propagated with the same line by line model. This approach is seldom used because of it's computation time. Actually, atmospheric radiation propagation is generally calculated using a narrow band model, which raises the problem of consistency between the target and background radiation calculations even if the band model and the line by line model have the same spectroscopic characteristics. Nevertheless this last method in also rarely used, and most of the time two independent codes (one for the background radiation propagation, the other one for the target emission propagation) are used.

For MATISSE we have chosen a method allowing a fine physical description for image calculation and moreover faster than the radiance computation for N*M independent lines of sight. The atmosphere is described by a grid containing all the atmospheric parameters (pressure, temperature, mixing ratio, …). Atmospheric source functions at each node of the grid including thermal emission, atmospheric and aerosol scattering as well as ground and cloud radiance are calculated. Then, these radiative quantities are propagated with a CK model for each of the N*M line of sight forming a spectral radiance image. For target radiation propagation, we use a line by line model whose thermodynamic input data come from the atmospheric grid. Background and target radiation are then propagated with the same geophysical environment. Moreover, in order to ensure the consistency between background and target propagation, CK parameters are computed by using the same line by line model and spectroscopic data base, and transmission computed with the two methods have been compared (CK method use Beer' law).

This paper give a brief description of MATISSE a shows the first calculated images. Section 2 presents the architecture of the code and the physical models. Section 3 shows some validation cases and the results are given in section 4.

2. CODE DESCRIPTION

2.1 Architecture

In order to reduce computation time, image calculation in MATISSE1.1 is divided in two phases : the initialization and the rendering.

The purpose of the initialization is to calculate all the radiative quantities (the atmospheric source functions, the extinction coefficients, the cloud and ground radiances) for all the scene whose spatial limit is provided by the user, thanks to an input file or a Graphical User Interface. These radiatives quantities are then stored in files. Of course, this initialization phase can be time consuming but it can be executed once for a large area and used for a lot of diverse observation geometries.

In the rendering phase, the radiance seen by the observer can be computed for several geometric configurations just by computing the propagation of the stored radiative quantities, with the condition that the field of view is contained in the spatial area of the initialization phase. This architecture allows multiple observation geometries computation without re-computing all of the radiative parameters in the scene being modeled. In this rendering phase, the user can ask for a cloud or soil texture model.

In this paper, the initialization and rendering phase are respectively described in subsections 2.3 and 2.4.

2.2 MATISSE internal database

For this version of MATISSE, the user has the ability to choose the observation geometry, the computation bandwidth, the date and time and the coverage of cloud ; but the geophysical description (atmospheric profile, aerosol type, cloud microphysic and soil properties) are issued from the MATISSE internal database. All of these data comes from measurements, publications, Universities research, and from organizations such as MétéoFrance (French weather forecast center), but are not directly usable in MATISSE. These are firsthand data that need to be adapted or transformed into secondary databases for use in MATISSE. This paragraph give a brief description of these database.

2.2.1 Atmospheric Profiles

The atmosphere in MATISSE is described by a thermodynamic and aerosol data set. The thermodynamic data consist of pressure, temperature and molecule mixture ratios profiles. These profiles are defined from the ground to the top of the atmosphere and are collected into three different data banks depending on their origin : 1D, 2D or 3D database.

In the 1D database the thermodynamic parameters are constant horizontally all across the scene, and only their vertical variability with altitude is considered. This data set includes more than 2500 profiles (TIGR database [1]) plus the seven usual MODTRAN profiles. The main source for these profiles are atmospheric radio-sounding. In the 2D database, the parameters are assumed to be constant for all longitudes within a given latitude band of $\Delta L \approx 10°$. For the 3D database the thermodynamic data vary in latitude and longitude with a spatial resolution of 0.25° x 0.25°, and variability with altitude is still present. The data come from outputs of MétéoFrance weather forecast codes. For the 1D and 3D case, the primary data give the temperature, water vapor and in some cases ozone, up to altitudes of 10 to

20 km. So these data need to be merged with the other atmospheric gaz profiles, and extrapolated up to the top of atmosphere (100 km). This is achieve using the PRFL [2] code, which contains a climatology of atmospheric profiles.

2.2.2 Aerosol Data

The aerosol data consist of absorption and scattering coefficients as well as the phase functions for the type of aerosols existing at each point of the atmospheric grid, with a spatial resolution of 5° x 5° for a set of eight relative humidities and two seasons. These data come from the GADS [3] climatology that provides the optical index of the particles as well as their size distribution. As optical properties depend on local relative humidity, they are calculated at run time using the chosen atmospheric data set humidity grid.

2.2.3 CK Profiles

Absorption is calculated in MATISSE with a Correlated K (CK) model [4]. The CK model coefficients are determined for the gas mixture of the atmospheric profile considered. In this way, the thermo-physical data (pressure, temperature and mixture ratios of the various molecules present) of a profile taken from the secondary data banks are replaced by a set of pre-calculated CK values defined for each spectral resolution element.

The coefficients in the CK model are generated in each 5 cm^{-1} spectral interval between 750 and 3300 cm^{-1}, for each pressure/temperature and gaseous mixture ratio belonging to the local atmospheric profile. These absorption coefficients are calculated using a line-by-line code [5] (so called RPR in this paper) and spectroscopic parameters from the Hitran96 database [6]. The number of K parameters for each spectral bin is 17.

2.2.4 BRDF, BTDF and emissivity cloud database

With the MATISSE code, it is possible to generate partial or total stratocumulus cover. The radiation calculations use the Independent Pixel Approximation approach (IPA) [7] with an horizontal spatial resolution of 500 m. The top and bottom of each resulting column are characterized by a Bidirectional Reflectance Distribution Function (BRDF), a Bidirectional Transmitance Distribution Function (BTDF) and an emissivity, so that cloud radiation can be computed both at the top and base of the cloud.

The BRDF, BTDF and emissivities are dependent on the wavenumber, the cloud's optical thickness and single scattering albedo, observation zenith angle and, solely for the BRDF and BTDF, on the solar zenith angle and on the relative azimuth between the sun and observer. They are calculated for a set of these input parameters with the RTRN21 [8] code, that uses the discrete ordinates method in a plane parallel geometry. These quantities are then stored in a database.

2.2.5 Ground Data

The ground data in MATISSE include the local elevations and local thermo-optical data for the terrain types. We use the Global Land Cover Characteristics (GLCC) database [9] that provides a reference to a type of terrain for each land cell with a spatial resolution of 30" arc at equator. A digital elevations model (GTOPO30) giving the local elevations with respect to WGS84 [10] and with a similar spatial resolution is also used. Combining the GLCC with that from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) [11] bank which contains the hemispheric spectral directional reflectance of many natural and artificial materials from 0.4 to 14 µm, we have assembled a secondary database. With it, we can extract the local optical properties of the terrain background with a spatial resolution of 30" of arc at the equator, and for global coverage.

2.2 Initialization phase

2.3.1 Calculation of the atmospheric source functions

Once the observer positions, viewing angles and the date are known, the program interrogates the secondary data banks in order to determine the thermodynamic parameters and the aerosol data at the nodes of the atmospheric grid. From the local relative humidity, the aerosols optical parameters are calculated.

Since each atmospheric profile is referenced to an equivalent CK profile, all of the quantities used for calculation of the atmospheric source functions are available at the nodes of the atmospheric grid. In MATISSE, the atmospheric source function is the sum of two distinct terms. The first one represents the local thermal emission and the second one the scattering of the radiation coming from all directions, with the exception of direct solar illumination. Calculation of the first term is achieved very easily, and is performed at all points of the atmospheric grid (for the 1D and 2D atmosphere the grid is the 5°x5° aerosol grid whereas in the 3D atmosphere, the grid spatial resolution is 0.25°x0.25°) resulting in a full 3D computation. The second one requires calculation of the radiation coming from all of the directions of the atmosphere, taking into account the radiation from the ground as well as the coupling of all the atmospheric layers. A rigorous approach would require a calculation of radiative transfer in 3D geometry, which would lead to considerable calculation times as a result. In MATISSE 1.1 we make the assumption that this term presents significant horizontal variations mainly at large scale, and so calculate it at lower spatial resolution. The atmospheric grid used is the 5°x5° aerosol grid and in each column we perform a one dimensional calculation with the RTRN21 code previously mentioned in a plane parallel geometry. This method is equivalent to the IPA.

2.3.2 Cloud radiation

A cloud generator is used to produce stratocumulus in the scene. Generator input data are the cloud cover ratio, the altitude of the base, assumed to be constant for the whole scene, and the maximum thickness of the cloud layer. At the output of the generator, we get the horizontal distribution of thickness h(x,y) of the cloud columns spread over the observed scene, as well as their liquid water path LWP(x,y), at the best horizontal resolution compatible with the size of the scene. The finest spatial resolution is limited to 500 m in order to conform to the radiative transfer assumptions. From the knowledge of the water content for each cloud column [12] and the molecular absorption, we can derive the values of the local optical thickness, as well as the single scattering albedo. Then, with local knowledge of the solar and observation angles, it is possible to calculate the cloud radiation using the BRDF, the BTDF and the emissivities associated with the local parameters from the internal cloud database.

2.3.3 Ground radiation

Depending on the geographical locations, the ground properties (reflectivity, emissivity and thermal data) are available in the internal MATISSE database for the whole Earth with a spatial resolution of 30" arc at equator.

Reflected direct solar radiation and diffuse atmospheric radiation are taken into account. For evaluation of the ground radiative emission term, a fast computation of ground temperature is performed. The radiative energy deposit is described by an analytical law between this quantity at ground level and the direct solar illumination at the zenith, taking account the aerosol type and the local relative humidity.

2.4 Rendering phase

The purpose of the rendering module is to compute the observed radiance at various sensor positions from the radiative quantities calculated in the initialization phase.

One of the main tasks of this module is to identify which facets are seen by the observer and which are illuminated by the sun. This module uses the OpenGL library and is thus able to operate both in software or hardware accelerated mode. The hardware mode (standard 3D graphical card) provides a real time 3D visual representation of the scene.

Once the observed and illuminated facets are known, all the radiative quantities are propagated toward the observer. At this stage, the first order scattering of the direct solar radiation radiance is computed. As for the thermal source function, the computation is performed at all points of the atmospheric grid in a full 3D geometry.

The image seen from the observer is a matrix of spectral or integrated radiance values, depending on the chosen option. For images requiring a spatial resolution which is greater than the resolution of the available data in MATISSE 1.1 (30’’ of arc at the equator for the ground backgrounds and 500 m for the clouds), the spatial rendering is artificially increased down to some ten meters by a texture module that uses a PSD (Power Spectral Density) approach. The texture model parameters where fitted on a set of airborne collection of high resolution infrared images of ground and cloud backgrounds.

In addition, if the user requests for radiance and transmission calculation along a line of sight, atmospheric refraction effects in the 3D atmosphere are taken into account.

2.5 Transmission at high spectral resolution

Sometime, it is necessary to calculate atmospheric transmission at very high spectral resolution. For example the CK model of MATISSE is not suitable to compute the transmitted radiation emitted by hot gases sources. To get around this problem, MATISSE contains the line-by-line model RPR (the same used for the CK parameters generation) which can be used instead of the CK along one line of sight.

2.6 Programming and development machine

The code is developed in C for the main program and some of the modules, while other modules (RTRN21 and the line-by-line code) are in Fortran 90. The Graphic User Interface (GUI) is developed in PVWAVE 7.0.
All of the code is developed using a quality management, which guarantees strict programming rules as well as a full set of documention and code testing.

The development machine is a Sun Ultra80 station, containing two 450 MHz processors, each with 500MB of memory.

3. VALIDATION

The validation strategy consists of comparing MATISSE 1.1 results with reference codes or/and with results obtained during measurement campaigns. In this section we show comparison results for the LBL model, the CK model and the cloud model only.

3.1 Radiative transfer models

As a first step in the validation process, we begin by the line-by-line model RPR. This model has been developed in the context of a thesis and compared with laboratory measurements [13]. Moreover, it has been compared with LBLRTM [14] and it appears that the two codes are in fair agreement for the majority of the tests. For the validation of the CK model alone, we use the RPR model as a reference code for the transmission and it appears the results are always in fair agreement for most cases.

Figure 1 shows a comparison between LBLRTM, RPR and the CK model. LBLRTM and RPR results are spectrally degraded by convolution with a triangular slit function. The observation altitude is 9km and the line of sight zenith angle is 103°15. For this comparison we use the US Standard atmospheric profile.

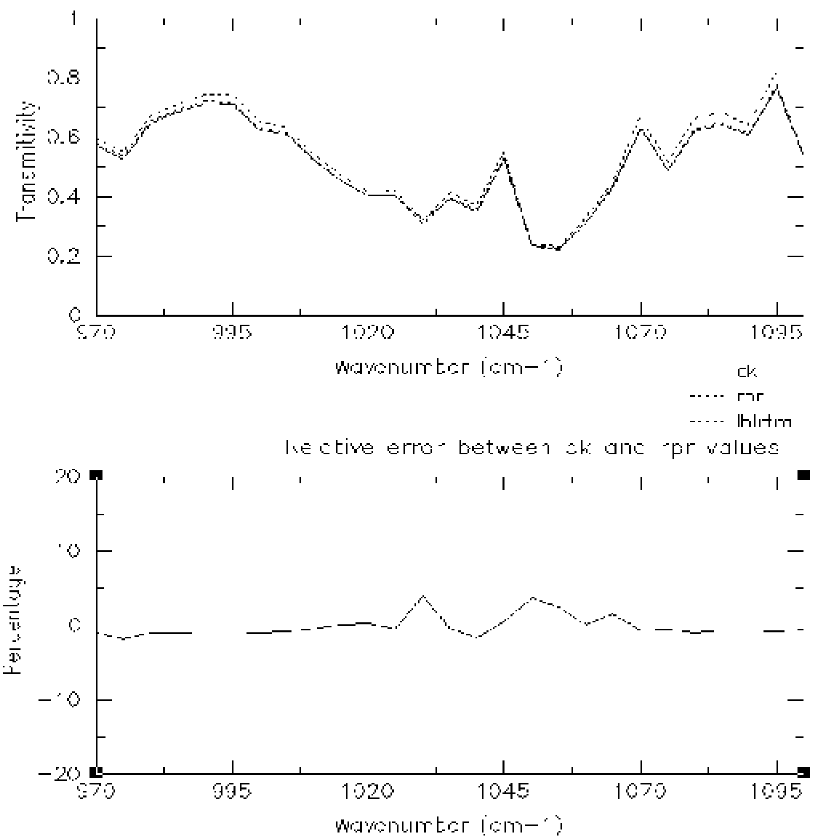

Figure 1 : RPR, LBLRTM and CK transmission comparisons

In the figure, we notice the comparison between RPR and the CK model are very good, the relative error is less than 5%. Nevertheless, we note a slight difference between LBLRTM and the two other codes (top figure). This difference is attributed to the fact that both codes don't use the same continua models : LBLRTM use the CKD model [15] whereas RPR use a model developed at the Laboratoire de Physique Moléculaire et Application in France.

In Figure 2 transmission obtained with the CK model (inserted in the MATISSE code) and MODTRAN3.5 [16] with the same observation conditions as previously are plotted. The results are in fair agreement but we observe some discrepancies for some wavelength ; calculations with RPR and LBLRTM agree with MATISSE's CK model. Note the transmission values in Figure 2 are lower than in Figure 1, because of the presence of climatological aerosols in MATISSE1.1.

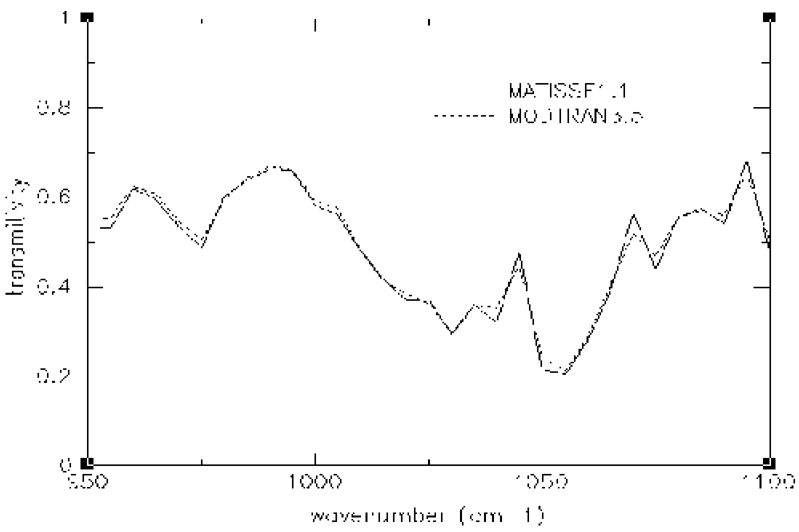

Figure 2 : MATISSE1.1 and MODTRAN3.5 total transmission comparison (molecule + aerosols)

3.2 Cloud model

Cloud spectral radiance calculated by MATISSE 1.1 is compared with experimental radiance measured by the SICAP spectrometer during ECRIN's campaign [17] in the 3-5 µm waveband. SICAP is an airborne infrared cryogenic spectrometer developed at ONERA, loaded in the Caravelle 116 of the CEV (french flight test center). The principle of the spectrometer is based on the use of a rotating filter with a continuously variable wavelength. The detector filter and the lens are cooled at the temperature of liquid nitrogen thus reducing the instrument background radiation. Its waveband is from 1.5 µm to 5.3 µm with a resolution $\Delta\lambda/\lambda$ equal to 2 %. For the comparison, we choose one cloudy pixel from a MATISSE image.

An exemple of MATISSE 1.1 calculation compared to SICAP measurements can be seen in Figure 3. The line of sight zenith angle is 120°, the relative azimuth betwen the sun and the observer is 27 ° and the aircraft is located at an altitude of 3.6 km.. As it can be seen, results are in good agreement. The slight discrepancy can be attributed to the fact that radiances emerging from all the facets are averaged in order to compare with measurements.

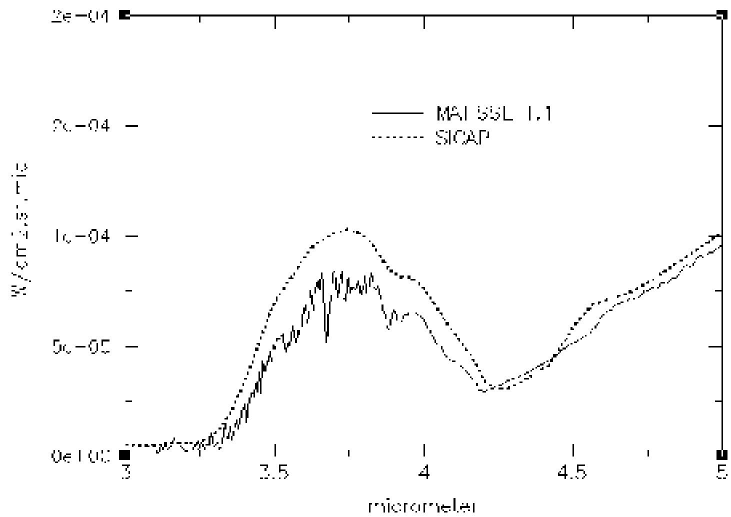

Figure 3 : MATISSE 1.1 and SICAP comparison

4. RESULTS

Next figures are images of the Corse island calculated by MATISSE1.1. The observer is located at an altitude of 100km and is looking down at nadir, in July at 13hTU. The observation field of view is 80°x80° and the number of pixels is 200x200.

Figure 4 is a transmission image at wavenumber 2700 cm^{-1} (3.7 µm) ; the darker the image, the lower the transmission. We observe the decrease in the transmission as we go away from the center of the image, corresponding to an increase of the distance between the observer and the sea level, which is an effect of the field of view. This image shows a good representation of the hilly Corse relief. Figure 5 is the corresponding radiance image. The sea is black (sea radiation is close to a blackbody colder than the ground) and the radiance variations on the ground are due to ground temperature variations, type of terrain variability and ground altitude variations.

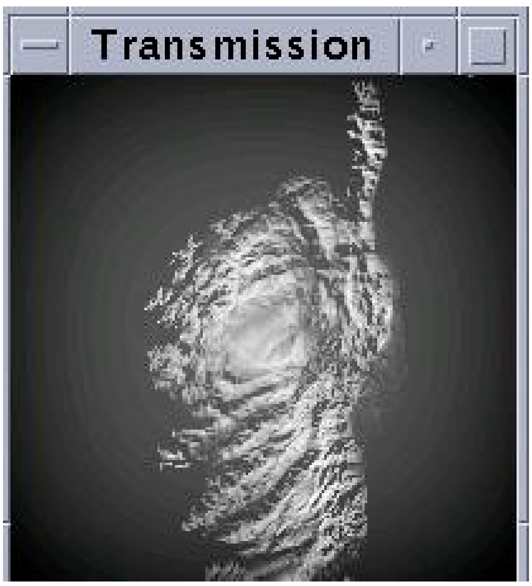

Figure 4 : Transmission image /σ = 2700 cm^{-1}

Figure 5 : Radiance image /σ = 2700 cm^{-1}

In Figure 6, the observation characteristics are the same as previously, but a 5% partial coverage of stratocumulus clouds is present. The radiance of the cloud located in the southwest of the coast (≈ 7.10^{-4} $W/m^2.sr.cm^{-1}$) is slightly higher than the sea radiance (≈ 5.10^{-4} $W/m^2.sr.cm^{-1}$). It is the opposite for the cloud located over the island (≈ 8.10^{-4} to 9.10^{-4} $W/m^2.sr.cm^{-1}$ for the cloud and ≈ 1.10^{-3} to $1.3.10^{-3}$ $W/m^2.sr.cm^{-1}$ for the ground around the cloud).

In the Figure 7 the wavenumber is 910 cm^{-1} (11µm). Sea radiance is ≈ 1.10^{-1} $W/m^2.sr.cm^{-1}$, cloud radiance ≈ 8.10^{-2} $W/m^2.sr.cm^{-1}$ and ground radiance ≈ 1.3 10^{-1} $W/m^2.sr.cm^{-1}$.

Running MODTRAN3.5 for one line of sight in the case of clear atmosphere (sea albedo ≈ 0.05 / ground albedo ≈ 0.05 to 0.2) or with a total coverage of stratocumulus clouds gives the same order of magnitude.

Figure6 : Scu cover / σ = 2700 cm^{-1}

Figure 7 : Scu cover / σ = 910 cm^{-1}

5. CONCLUSION

This paper explains briefly the main features of MATISSE1.1 and exhibits the first generated images. The purpose of the code is to calculate radiance images including the spatial variability of the atmospheric quantities as well as radiation from the ground and from stratocumulus clouds. For these two backgrounds, a texture model is implemented in order to increase the image spatial resolution. The spectral range spreads from 760 to 3300 cm^{-1} (3 to 13µm), with a resolution of 5 cm^{-1}. Main outputs are radiance and transmission images. Radiance and transmission calculations along one line of sight is also possible ; in this case the code takes into account refraction effects. MATISSE 1.1 also allows to compute transmission at high spectral resolution along a line of sight in order to propagate fires or plumes radiation.

Results are compared with reference codes. In this paper we show comparisons of the calculated transmission by the MATISSE CK model and the line by line model, and also with MODTRAN3.5. A comparison between cloud radiation and experimental results is also shown. Radiance images are presented in clear atmosphere, or with a low coverage of clouds for two wavenumbers 2700 cm^{-1} and 910 cm^{-1}.

ACKNOWLEDGMENTS

MATISSE 1.1 is sponsored by the Délégation Générale pour l’Armement in France and ONERA. Acknowledgments to Michael Dana for line by line and CK comparisons.

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