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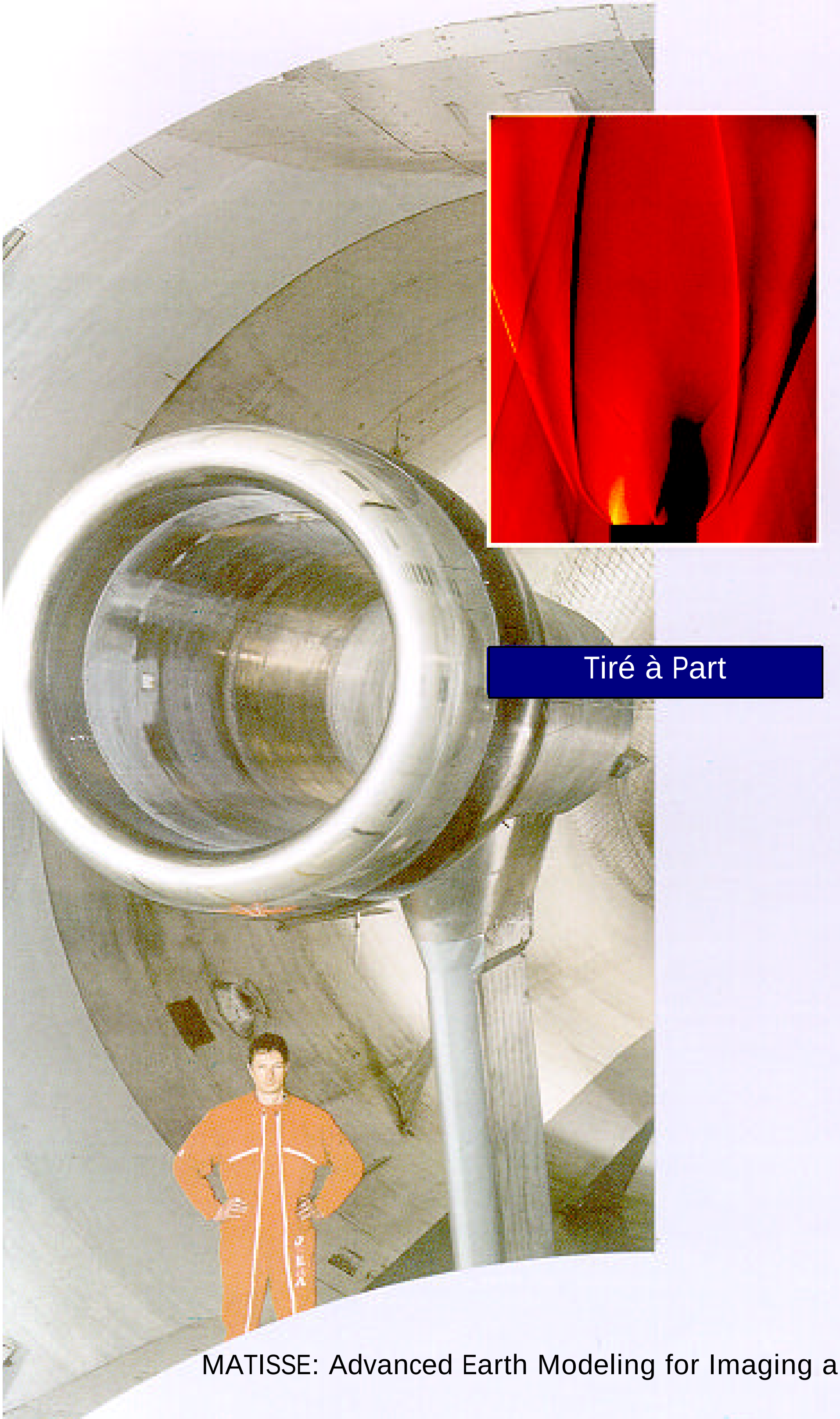

Tiré à Part

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MATISSE: Advanced Earth Modeling for Imaging and Scene Simulation

MATISSE : Modélisation Avancée de la Terre pour l'Imagerie et la Simulation des Scènes et de leur Environnement

par

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Résumé : Le but de MATISSE1.1 est le calcul d'images en luminance spectrale ou intégrée de fonds naturels, ainsi que la transmission d'une signature de gaz chaud. La bande spectrale pour cette version s'étend de 750 à 3300 cm^{-1} (3 à 13 µm) avec une résolution de 5 cm^{-1}. L'absorption gazeuze est calculée avec un modèle en K corrélé (CK). La variabilité spatiale des grandeurs atmosphériques (température, rapports de mélange, ...) est prise en compte par l'utilisation de profils atmosphériques évoluant le long de la ligne de visée.

Les fonds naturels sont constitués du fond atmosphérique, des nuages basse altitude et du fond de sol. Les modèles de rayonnement utilisés sont adaptés à la basse résolution spatiale, ce qui a motivé l'insertion d'un modèle de texture en luminance afin d'accroître la résolution spatiale au domaine décamétrique.

Des sorties intermédiaires du programme permettent d'obtenir la luminance et la transmission le long d'une seule ligne de visée, auquel cas les effets de réfraction sont pris en compte. Le long de cette ligne de visée la transmission peut être calculée en utilisant un modèle raie par raie, afin de pouvoir propager le rayonnement issu d'une signature de gaz chaud (feux, jet d'avion ou de missile).

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MATISSE
Advanced Earth Modeling for Imaging and Scene Simulation

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ABSTRACT

The purpose of MATISSE 1.1 is to compute spectral or integrated radiance images of natural background, as well as the transmission of a hot gas signature. The spectral bandwith 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 (CK) model. The spatial variability of atmospheric quantities (temperatures and mixing ratios, among others) is taken into account by 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 decametric 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 usefull to propagate the radiation emitted by a hot gas signature (fires, aircraft or missile plume).

1. INTRODUCTION

The need to predict target detection performance by electro-optic sensors has prompted many works for the calculation of the contrast between targets and background. This contrast usually requires two independent calculations: one for the background radiance and another to find the transmitted radiation of the target. Moreover, for imaging sensors, the contrast has to be calculated with respect to an inhomogeneous background.

Most of today's atmospheric radiation codes [1],[2] can only calculate propagation along a single line of sight (one calculation for each pixel) and assume an horizontally homogeneous atmosphere. This propagation is generally calculated with band models to reduce computation time. But 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 for the correct calculation of the atmospheric transmission. If the line-by-line model is chosen, the two calculations (background and target propagation) will be matched for consistency, *i.e.*, the background radiance calculated at a given wave number will be transmitted at the same wave number. Nevertheless, this approach is seldom used with broadband sensors because of it’s computation time. On the other hand, if a specific narrow band model is used for the target propagation, this band model has to be inserted in the atmospheric radiation code (in order to have the same atmospheric properties) and has to be coherent with the inner band model of the atmospheric code.

Lastly, all the available atmospheric radiation codes don’t take into account 3D atmospheric spatial variability.

To meet these requirements, a work program was launched in 1996 to create the MATISSE code (MATISSE standing for 'Advanced Earth Modeling for Imaging and Scene Simulation'). The first objective of this code was to compute transmission and atmospheric radiance along an optical path in an atmosphere exhibiting geographically variable thermodynamic properties with a fast computing method for the radiation propagation. This prototype version has been used to test the reliability of the propagation calculation in a 3D atmosphere. However, it was based on a calculation of the radiance along a *single* line of sight for evaluating local contrasts, and was thus ill-suited to generating radiance images. The computations for a 256 x 256 pixels sensor would entail 65536 independent radiance calculations and a considerable amount of time. Therefore upgrading the code to compute scenes quickly while retaining a fine physical description within the scene has been our major concern. This led to MATISSE v1.1, the architecture of which is covered in this paper.

2. CODE DESCRIPTION

2.1 Architecture

The program 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) with input data drawn from the code's internal databases, and other data provided by the user. These radiatives quantities are then stored in files. Of course, this initialization phase can be time consumming and methods have been developed to minimize this computation time.

In the rendering, the radiance seen by the observer can be computed for several geometric configurations just by computing the propagation of these stored radiative source functions, which is faster than re-computing all of the radiative parameters in the scene being modeled.

2.2 Initialization step

In this first step, the input data are used for the calculation of the atmospheric source functions, the clouds and the ground radiances. We describe hereafter these database and the methods developed for radiance computation.

2.2.1 Input Data

There are two kinds of input data: data provided by the user, and the code's internal data. The former express the observation conditions specified by the user (observer's position, sighting angles, date and time, spectral bandwidth, among others) while the latter describe both the geophysical environment (atmospheric profiles, aerosol types, cloud parameters, terrain types) and the quantities needed to compute the propagation (CK model coefficients). All of these data comes from 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.

2.2.1.1 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 [3]) plus the seven usual MODTRAN profiles. 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 done using the PRFL [4] code, which contains a climatology of atmospheric profiles.

2.2.1.2 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 [5] 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.

2.2.1.3 CK Profiles

Absorption is calculated in MATISSE with a Correlated K (CK) model [6]. The CK model coefficients are determined for the gas mixture of the atmospheric profile considered. This is equivalent to considering a fictitious molecule whose absorption spectra would be equal to that of the local molecules mixture. 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 development of the CK database can therefore be viewed as a conversion from a thermodynamic representation of the atmospheric profiles to an optical properties profile. Of course, the dependency of the absorption coefficient with the wavenumber requires the introduction of a new parameter corresponding to the central frequency at which the calculation is made.

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 [7] and spectroscopic parameters from the Hitran96 database [8].

2.2.1.4 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)[9] with an horizontal spatial resolution of 500 m. The top and bottom of each resulting column are characterized by a Bidirectional Reflectivity Distribution

Function (BRDF), a Bidirectional Transmissivity 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 [10] code, that uses the discrete ordinates method in a plane parallel geometry. These quantities are then stored in a database.

2.2.1.5 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 [11] 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 [12] and with a similar spatial resolution is also used. Combining the GLCC with that from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (Aster) [13] bank which contain 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.

2.2.2 Calculation of the atmospheric source functions

Once the user specified list of target positions, observer position 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 optical parameters of the aerosols are calculated. Since each atmospheric profile is referenced to the equivalent CK parameters profiles data bank, all of the quantities used for calculation of the atmospheric source functions are available at the nodes of the atmospheric grid.

The atmospheric source function is the sum of three distinct terms. The first one represents the first order scattering of the direct solar radiation, the second one the local thermal emission and the last one the scattering of the radiation coming from all directions, with the exception of direct solar illumination. Calculation of the first two terms is achieved very easily, and is performed at all points of the atmospheric grid. The third 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 horizontal variation mainly at large scale, and so calculate it at lower spatial resolution. The atmospheric grid used has an horizontal resolution of 5°X5°, which is consistent with the resolution of the GADS aerosol data set. In each column we perform a calculation with the RTRN21 code previously mentionned.

2.2.3 Cloud radiation

The stratocumulus cover is performed with a cloud cover generator. The entry input data of this generator 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 assumptions made for calculation of the radiative transfer. From the knowledge of the water content for each cloud column [14] and the molecular absorption, we can derive the values of the local optical thickness, as well as the single scattering albedo. 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

2.2.4 Ground radiation

Depending on the geographical locations, the quantities characterizing the ground (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 deposition of radiative energy is described by an analytical law which associates this quantity at ground level with the direct solar illumination at the zenith, taking account of the type of aerosol and of the local relative humidity.

2.3 Rendering module

The purpose of the rendering module is to calculate the radiance observed at 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 of radiative quantities are propagated toward the observer. The image at the level of the observer is a matrix of spectral or integrated radiance values, depending of with option is chosen. For images requiring a spatial resolution which is greater than the resolution of the data available 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 is taken into account.

2.4 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 for the transmission of radiation from hot gases sources. To get around this problem, MATISSE contains a line-by-line model (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 process, 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

In a first stage, the validation strategy consists of comparing the results obtained with MATISSE 1.1 and other codes for particular conditions of computations. As an example, the atmospheric radiation calculated with MATISSE 1.1 will be compared with the radiance calculated by FASCOD3P [15] (spectrally degraded) in a 1D atmosphere, since the latter code does not have the ability to take account of the atmospheric spatial variability. A similar comparison will be carried out between the line-by-line approaches of MATISSE and FASCOD3P.

Physical validation will be achieved by experimental campaigns, during which spectral radiative measurements in the infrared will be carried out in correlation with in situ measurements. Some campaigns have been performed by Onera [16], or results from others are available in the literature [17],[18].

4. CONCLUSION

The MATISSE v1.1 code currently being developed at ONERA is expected to complete beta testing by may 2002. The purpose of the code is to calculate radiance images of background including the spatial variability of the atmospheric quantities as well as radiation from the ground and from stratocumulus clouds. The spectral range is from 3 to 13 µm, with a resolution of 5 cm^{-1}. It is also possible to calculate transmission at high spectral resolution along a line of sight in order to propagate fires or plumes radiation. Some of the modules presented in this paper are still being optimized and tested, which means that they are still subject to modifications.

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