The coupling of MATISSE and the SE-WORKBENCH: a new solution for simulating efficiently the atmospheric radiative transfer and the sea surface radiation

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ABSTRACT

The SE-WORKBENCH workshop, also called CHORALE (French acceptation for “simulated Optronic Acoustic Radar battlefield”) is used by the French DGA (MoD) and several other Defense organizations and companies all around the World to perform multi-sensors simulations. CHORALE enables the user to create virtual and realistic multi spectral 3D scenes that may contain several types of target, and then generate the physical signal received by a sensor, typically an IR sensor.

The SE-WORKBENCH can be used either as a collection of software modules through dedicated GUIs or as an API made of a large number of specialized toolkits.

The SE-WORKBENCH is made of several functional block: one for geometrically and physically modeling the terrain and the targets, one for building the simulation scenario and one for rendering the synthetic environment, both in real and non real time.

Among the modules that the modeling block is composed of, SE-ATMOSPHERE is used to simulate the atmospheric conditions of a Synthetic Environment and then to integrate the impact of these conditions on a scene. This software product generates an exploitable physical atmosphere by the SE WORKBENCH tools generating spectral images. It relies on several external radiative transfer models such as MODTRAN V4.2 in the current version.

MATISSE [4,5] is a background scene generator developed for the computation of natural background spectral radiance images and useful atmospheric radiative quantities (radiance and transmission along a line of sight, local illumination, solar irradiance …). Backgrounds include atmosphere, low and high altitude clouds, sea and land. A particular characteristic of the code is its ability to take into account atmospheric spatial variability (temperatures, mixing ratio, etc) along each line of sight. An Application Programming Interface (API) is included to facilitate its use in conjunction with external codes.

MATISSE is currently considered as a new external radiative transfer model to be integrated in SE-ATMOSPHERE as a complement to MODTRAN. Compared to the latter which is used as a whole MATISSE can be used step by step and modularly as an API: this can avoid to pre compute large atmospheric parameters tables as it is done currently with MODTRAN. The use of MATISSE will also enable a real coupling between the ray tracing process of the SE-WORKBENCH and the radiative transfer model of MATISSE. This will lead to the improvement of the link between a general atmospheric model and a specific 3D terrain.

The paper will demonstrate the advantages for the SE WORKEBNCH of using MATISSE as a new atmospheric code, but also for computing the radiative properties of the sea surface.

Keywords: Infrared simulation, SE-WORKBENCH, MATISSE, ray tracing, atmospheric radiative transfer, simulation of the sea surface

1. INTRODUCTION

1.1 Overall presentation of the SE-Workbench

The SE-WORKBENCH, also called CHORALE, is a multi-sensor battlefield modeling workbench mainly used by French DGA, German BWB and by South Korea MoD, in order to achieve the synthesis of 3D scene observed by a sensor, this in two steps:

- The physical characterization of the 3D scene behavior
- The Computation of the physical signal received by a sensor

The SE-WORKBENCH is entirely based on software products developed by OKTAL-SE and realize the multi-spectral unification of optronics, electromagnetism and acoustics, using a common kernel & physical extensions affectation both aimed at a unique 3D scene and a common technology. The SE-WORKBENCH is a winning initiative for sharing R&D efforts and federating a user group community that intends to exchange experience and knowledge.
The first development was in 1994 and has been strongly boosted by the French SCALP missile program and the qualification of the IR tracking system. At the beginning, the SE-WORKBENCH was focused on the IR domain. In 2003, an acoustic version already described in previous SPIE conferences, has been developed. In 2001, an electromagnetic version of the workshop was initiated, with the help of ONERA French research center, mainly focused on millimeter waves and wide scenes, typically for SAR applications.
The control of the SE-WORBENCH validity domain is based on both a theoretical validation approach (development of physical models, general modeling and simulation knowledge, elementary tests and validity assessment) and a validation process based on comparisons with experiments (SCALP/EG missile [FR], Storm Shadow missile [UK], AASM missile [FR]).

1.2 The SE-WORKBENCH-IR

The SE-WORKBENCH-IR is made of different components, as described hereafter, corresponding to the successive steps of a IR sensor simulation that are the modeling, the scenario edition, the rendering without the sensor effects and finally the sensor transfer function simulation. Furthermore, the user can do software integration in order to control the generated scenario execution from a remote or custom application. This can be achieved with the help of the SE-TOOLKIT consisting of a set of libraries and application programming interfaces (API) to help the complex application design and integration.

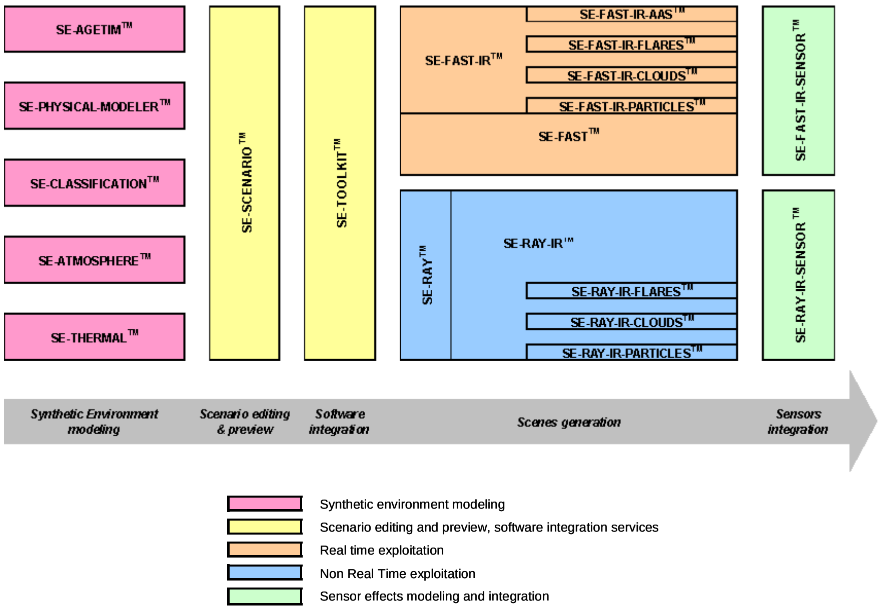

Fig. 1: The SE-WORKBENCH-IR components.

1.3 SE-WORKBENCH-IR tools

SE-AGETIM

The SE-AGETIM (*Synthetic Environment Multisensor Terrain Generation Tool*) product is an integrated software that enables the generation of 3D synthetic environment with a user specified resolution and realism. It provides the user with a unique way of integrating heterogeneous geographical data to produce a coherent 3D database. Corrections and enhancements can be applied on source data. The SE-AGETIM product is based on a reference of the market Geographical Information System (GIS) for its user interface.

Fig. 2: Example of a 3D virtual mock-up generated using SE-AGETIM.

SE-PHYSICAL-MODELER

The SE-PHYSICAL-MODELER (Synthetic Environment Physical Modeler) product enables the 3D synthetic environment developer to easily characterize the elements of the scene in terms of their physical properties. It gets state-of-the-art display capabilities, including interactive 3D visualization window based on Open-Inventor. The visualization windows are updated when modifying mapping or material. All the material used can be shown with a palette editing, with spectral and thermal characteristics graphic display.

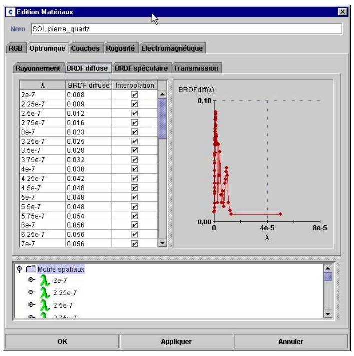

Fig. 3: Infrared material physical properties edition.

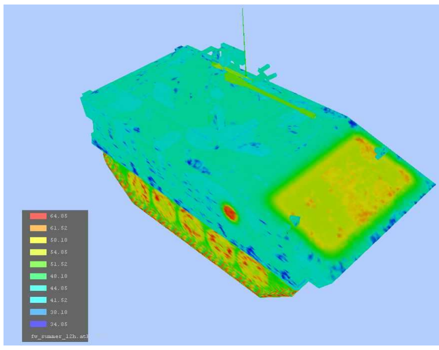

Fig. 4: Visualization of temperatures

SE-CLASSIFICATION

The SE-CLASSIFICATION (Synthetic Environment Classification) product is used to classify texture of physical materials. The picture to be classified is decomposed in layers. For example, for a wall picture, one “roughcast” layer, one “window” layer and one “shutter” layer are created. For each layer, a material modulation is computed. For the “window” layer, brown pixels are associated with the “wood” material, and the others ones with the “glass” material.

The classification panel, taking advantage of photo-interpretation, enables to select a color by picking on the picture and then to associate it to a physical material. To check the spectral behavior of materials in use, and to get an idea of the result, a visualization panel enables the pre-view of the physical classification effect.

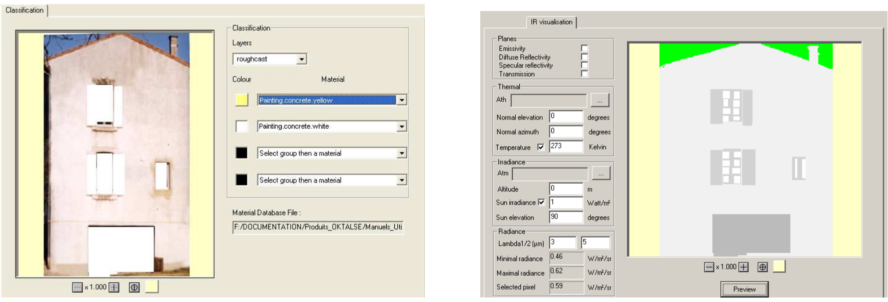

Fig. 5: Textures classification panel as function of a material library and pre visualization window

SE-THERMAL

The thermal software (SE-THERMAL) enables the pre-calculation of all the possible temperature states of a scene at a given time of the day for a given atmosphere (SE-ATMOSPHERE). It also contains a module that enables the thermal shadow calculation (SE-THERMAL-TSC).

The thermal software takes into account, the history of atmospheric conditions, a decomposition in layers of the polygons and, for each layer, the thermal attributes (conductivity, specific heat, thickness, convection coefficients, …), two kinds of polygons: “terrain polygons” and “wall polygons” (for which an inner temperature or an inner heat flux can be defined by the user), the wind and its direction.

SE-SCENARIO

The scenario construction & preview stands between the modeling phase and the scene generation process, the user can build scenarios that will be helpful for the scene specification. Static scene generation can be expensive in terms of calculation time.

The advantage of the scenario is the ability for the user to place the sensors, to fine-tune their positions and the overall control (SE-SCENARIO). Trajectories can be assigned to sensors through the same user interface.

The SE-SCENARIO tool is an interactive 3D database analysis and scenario preparation tool. It also contains preparation, logger and playback functions. It can be used to edit SE-Advanced-Scene and SE-Fast-Scene scenarios for visible, infrared, electromagnetic and acoustic simulations. It offers the possibility to control position, orientation and behavior of sensors and objects, even to edit the trajectory of a moving element.

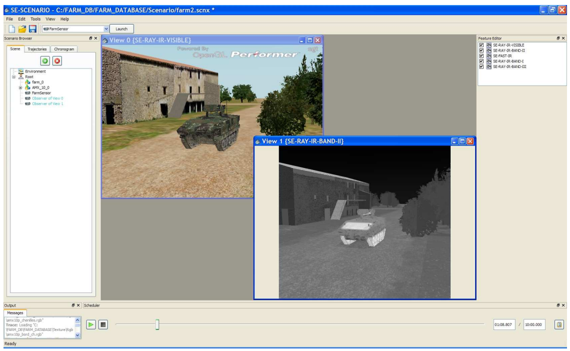

Fig. 6: SE-SCENARIO GUI

Non real time rendering based on SE-RAY-IR

SE-RAY is the ray tracing kernel developed by OKTAL-SE which enables to compute high realism images in several spectral domains. SE-RAY-IR is dedicated to the rendering of synthetic environments in the IR domain and is based on SE-RAY ray tracing kernel. The great originality of SE-RAY comes from the model based on physics. SE-RAY uses elementary pyramids defined by four adjacent rays (one basic pixel) which allows one to compute elementary surfaces and solid angles.

Besides SE-RAY-IR takes into account the wavelength sampling. Actually SE-RAY-IR works wavelength by wavelength. Time consumption is very optimized using SE-RAY. Actually performances are nearly independent on scene complexity. To do this SE-RAY uses a spatial subdivision method that enables to get a perfect knowledge of the scene topology before computing the first image. The scene space is decomposed in a hierarchy of volume elements (voxels) and then turned into a recursive space of voxels that improves efficiently the intersection computations. The solution to improve image quality mainly consists in over sampling by tracing more rays. The method adopted for SE-RAY-IR is the adaptative one. The most important antialiasing criteria are the following: number of different polygons in the pixel, number of different materials, normal vector variation within the pixel. Based on generalization of texture definition to any physical data, SE-RAY-IR can simulate the variation of specular reflectivity with the observation angles.

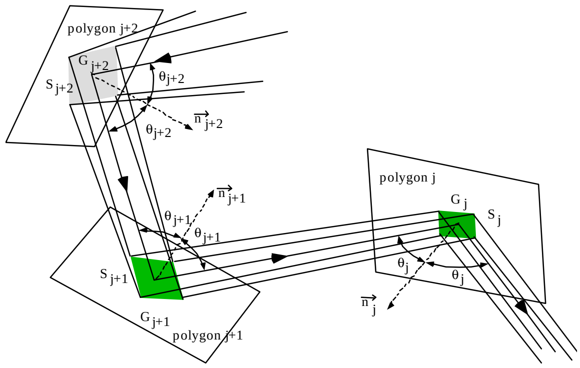

Fig. 7: Management of ray tubes in SE-RAY-IR

Concerning the physical IR model, SE-RAY-IR can take the following contributions into account:

- The thermal emission
- Diffuse and specular reflections
- Direct Sun lighting: Direct sun or moon lighting takes into account the atmospheric attenuation and diffusion between the astral source and any point in the 3D scene. An external data file (typically based on LOWTRAN or MODTRAN) contains attenuation and diffusion values for discrete values of the wavelength and of the altitude.
- Diffuse Sun lighting and sky/ground illumination: Sky and ground are considered as a global entity providing energy in any space direction. When loading the database, the canopy is tessellated in discrete solid angles defined using elevation and azimuth angles.
- Self emission of the atmosphere: An external data file (typically based on LOWTRAN or MODTRAN) contains atmospheric radiance data for discrete values of wavelength, altitude, elevation, azimuth and range. For each ray, both primary, secondary or lighting ray, the best value of atmospheric radiance is determined using linear interpolation.
- Atmospheric attenuation: An external data file (typically based on LOWTRAN or MODTRAN) contains atmospheric attenuation for discrete values of wavelength, altitude, elevation and range. For each ray, both primary, secondary or lighting ray, the best value of atmospheric attenuation is determined using linear interpolation
- Sky, horizon and cloud cover: Sky and horizon is a pure analytic model.

Real time rendering based on SE-FAST-IR package

The SE-FAST-IR package is made of a major product (SE-FAST-IR) and additional modules depending on the considered application.

With the help of some pre-calculation steps, real time images are computed with the SE-FAST-IR solution. It is dedicated to the computation of image sequences for near infrared sensors (light intensifying) and thermal infrared systems with short, medium or long waves (SWIR, MWIR, LWIR). The products make use of the results of the SE-CLASSIFICATION tool, the SE-PHYSICAL-MODELER modeler and the SE-ATMOSPHERE atmospheric files computation product. The thermal pre-calculations are based on SE-THERMAL code.

The previous version of SE-FAST-IR was based on a pre computation of the whole 3D scene with specific radiance texture adapted to a given waveband for a given spectral response. The real time process only consisted in using Open GL laws basically for non-static parts of the scene (for instance the specular parts, or the moving objects) and for the atmosphere propagation modeling depending on elevation, azimuth and range.

The new release of SE-FAST-IR brings a technological rupture by using OpenGL pixel shaders enabling direct calculation on 3D graphic cards. A shader is a procedure written in a special purpose high-level language that replaces a part of the graphic pipeline of a 3D graphic board.

SE-WORKBENCH APIs

The SE-WORKBENCH can be used either as a collection of software modules through dedicated GUIs or as an API made of a large number of specialized toolkits.

The SE-TOOLKIT is made of a set of libraries and application programming interfaces to help the complex application design and integration. The main objective of this library is to provide the user with the maximum of assistance while integrating hardware and software in the loop simulations. In that frame, the programming library has been developed in order to be able to answer customer requests for taking control of the SE-FAST-IR and SE-RAY-IR products from an external application without having to recompile or change/adapt the application code.

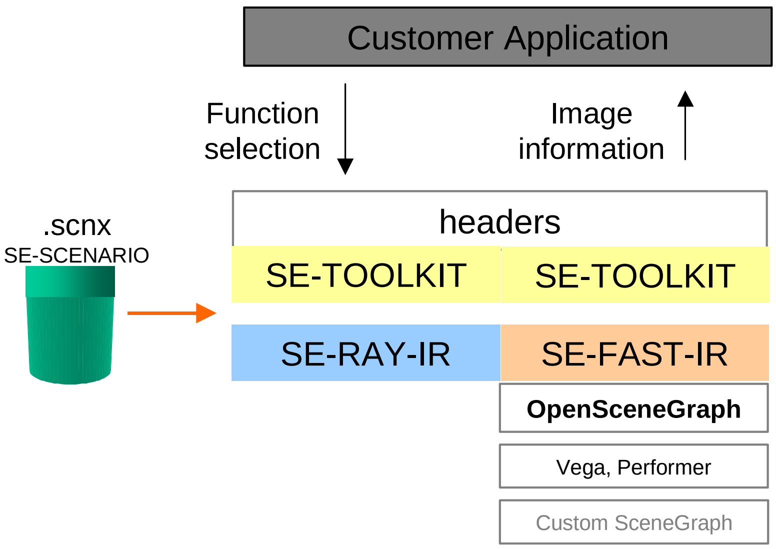

Fig. 8: Illustration of the use of SE-Workbench toolkit.

The SE-TK-FORM is a set of advanced APIs dedicated to the manipulation of the SE-Workbench static file formats. It enables to read and write custom data into the SE-Workbench formats for most of the applications. The SE-TK-FORM advanced API enables to manipulate the static formats of the SE-Workbench. It enables to read / write or exploit the formats for the geometry (SDM), the physical materials (MAT), the atmospheric files (ATM), the thermal files (TH), the trajectories (TRJ) and the output files from SE-RAY (SPS).

SE-TK-FORM-ATM enables to make use of measured properties of the atmosphere (solar flux, air temperature, wind properties, …) to create the corresponding atmospheric file as if created with the SE-ATMOSPHERE software. This enables to be closer to measurement for cross comparison.

1.4 SE-ATMOSPHERE

Overall presentation

The SE-ATMOSPHERE software allows the user to characterize the atmosphere. In its current version it can be used to parameterize the LOWTRAN and MODTRAN kernels as well as a generic atmospheric model whose physical model has been developed by OKTAL-SE in cooperation with CELAR. It can ease the edition of the configuration files with the help of a JAVA based user interface that avoids parameterization errors.

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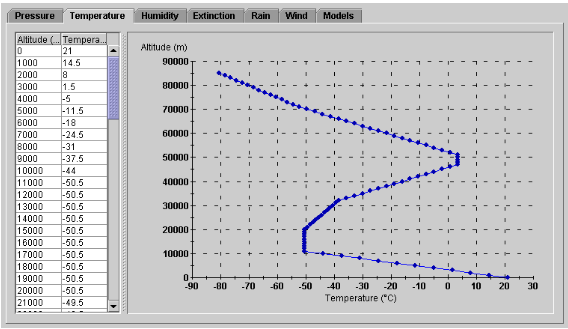

Fig. 9: Atmospheric profile parameterization window

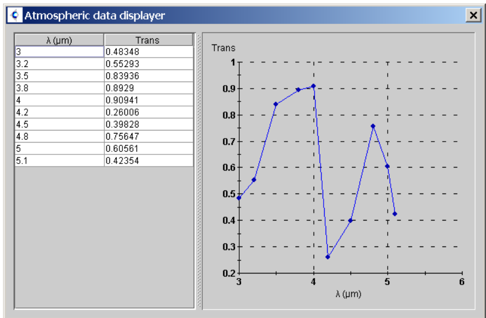

Fig. 10: Atmospheric data display window

The SE-ATMOSPHERE software computes:

- A table of spectral data of sun/moon irradiance for a list of altitude h_j and a list of wavelength λ_i
- A table of atmospheric transmission for a list of wavelengths, altitudes, and Lines of Sight (LOS)
- A table of sky radiance for a list of wavelengths, altitudes, and LOS.

These data are stored in a file and used by:

- The scene generation software (SE-RAY-IR and SE-FAST-IR) for the computation of atmospheric transmission, sun/moon irradiance and sky radiance
- The thermal software (SE-THERMAL) for the computation of incident fluxes.

SE-ATMOSPHERE features

- Exploitation of validated models for atmosphere like MODTRAN and an empiric model
- Well adapted for the visible and infrared synthetic environment modeling
- An easy and efficient user interface for the parameterization of all the supported models
- Errors prevention with a set of « default » parameters given to the user as function of his selection
- A database of pre-computed (thermal and radiative) atmospheric files available on demand

- Selection of Global parameters: date, latitude, longitude, global atmospheric model, average wind speed, ground altitude, …
- Time dependant parameters: haze, clouds, rain, wind (speed and direction), visibility range
- Sampling capabilities: Wavelength sampling of azimuth, elevation, range and altitude for the calculation of: solar/lunar irradiance, atmospheric attenuation and sky radiance
- Availability of template configuration files for basic wave bands (visible, SWIR, MWIR, LWIR)
- Import formats: User defined parameters, LOWTRAN, MODTRAN
- Export formats: ATM (internal format for SE-THERMAL, SE-THERMAL-SHADOWS and SE-RAY-IR software).

2. PRESENTATION OF MATISSE

MATISSE (Advanced Modeling of the Earth for the Imaging and the Simulation of the Scenes and their Environment) is a natural background scene generator. It is developed to meet the requirements of natural background radiance images and useful atmospheric radiative quantities (radiance and transmission along a line of sight, local illumination, direct solar irradiance …) computation. MATISSE is developed to generate reference images, using efficient methods in terms of accuracy and computation time and also using consequent database for the description of the environment (atmospheric parameters, land uses, clouds …).
The current version, MATISSE-v1.5, may be used in four computation modes:

1. an imaging mode for the computation of spectral radiance and transmission images of natural backgrounds, with a moderate spectral resolution;
2. a line of sight (LOS) mode for the direct computation of the spectral radiance and transmission along a LOS with a moderate spectral resolution;
3. an application programming interface (API) providing spectral radiance and transmission along a LOS with a moderate spectral resolution as well as other useful radiative, geometrical or atmospheric quantities;
4. a high spectral resolution mode, providing thermal radiance and transmission along a LOS using a line by line method.

All these four modes have the following functionalities:

- Spectral bandwidth from 700 to 25000 cm^{-1} (0.4 to 14µm) with an tunable spectral resolution for the moderate spectral resolution model (highest resolution is 1 cm^{-1}).
- Spectral bandwidth from 700 to 25000 cm^{-1} for the high spectral resolution model, with an automatic computation of the spectral resolution according to local thermodynamic conditions (typically from 0.1 to 0.005 cm^{-1}).
- Ability to treat 3D atmospheric scenes.
- Large atmospheric database (atmospheric thermodynamic profiles and aerosols).
- Cloud radiation computation including the superimposition of two cloud layers and a large choice of cloud types.
- Cirrus clouds modeling with realistic Hexagonal ice crystals.
- Ground modeling with the choice of 3 spatial resolutions.
- Ground temperature computation with local atmospheric conditions.
- Direct local irradiance computation.

MATISSE-v2.0 has the MATISSE-v1.5 functionalities, but the architecture has been modified to be able to treat spatial multi resolution in the generated images, in order to meet the requirements in sea surface infrared radiance images generation containing metric spatial variability.

3. THE COUPLING OF MATISSE AND THE SE-WORKBENCH

3.1 Coupling mechanisms

MATISSE in SE-ATMOSPHERE

For the coupling of MATISSE with the CHORALE code, a module has been developed in C language to generate the atmospheric files in the required “atm” format. This module has been tested by the DGA and is already operational for their applications.

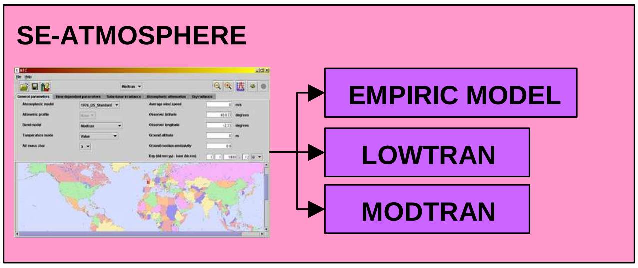

Fig. 11: Current version of SE-ATMOSPHERE.

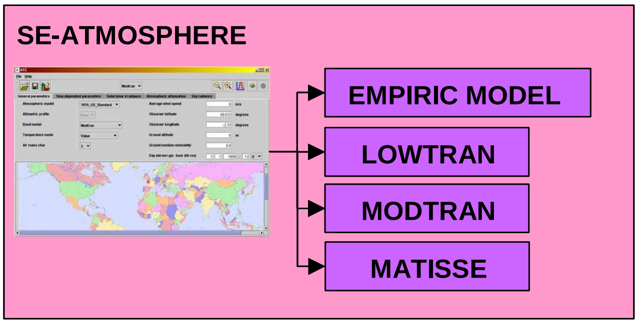

Fig. 12: Future version of SE-ATMOSPHERE.

Coupling with SE-RAY-IR through MATISSE API

MATISSE-v1.5 contains a library of 14 functions allowing a direct access to the code outputs and internal data. This API was developed for direct coupling with other codes purposes.
These functions developed in C language give access to radiative properties along a LOS, local illumination, solar irradiance, ground temperature, local atmospheric profiles, direction of the horizon …
This API is already used for coupling with the CRIRA code (Aircrafts Infrared Signature code), CHORALE and hyperspectral imaging applications.

In the case of the non real time rendering software SE-RAY-IR, the direct coupling with MATISSE can be considered to take advantage of the 2D or 3D capabilities of MATISSE: ability to take into account atmospheric spatial variability along each line of sight (cf. § 3.2 "Enhanced atmospheric data base") and to avoid the pre-computation of a huge amount of atmospheric data.

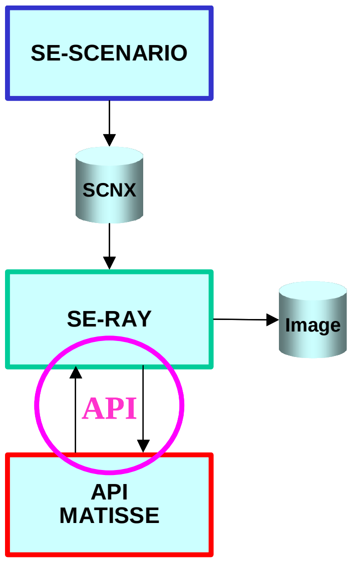

Fig. 13: Coupling through MATISSE API

3.2 New features provided by MATISSE in the SE-WORKBENCH

Simulation of cloud layers

In order to improve modeling in cloudy situations, MATISSE includes a large variety of clouds. Modeled clouds are Cumulus, Cumulus Congestus, Stratus (2 kinds), Stratocumulus (3 kinds), Nimbostratus (2 kinds), Altostratus and Cirrus (4 kinds). All these clouds are modeled with spherical liquid water or ice particles assumption. In addition, six Cirrus clouds with realistic hexagonal column ice particles are integrated in the code. Their radiative properties come from a database developed specifically for MATISSE by the "Laboratoire d'Optique Atmosphérique" in France and ensures a good representativity of the Cirrus clouds radiation.

Nevertheless, in this version of MATISSE, even if clouds properties are dependant on altitude it is assumed that the cloud layers are horizontally homogeneous. Consequently, there is no horizontal spatial variability of the cloud emerging radiation.

In addition, the code can take into account two superimposed cloud layers, like frequent high and low altitude cloud covers.

Enhanced atmospheric data base

A useful feature of MATISSE is its atmospheric profile database, allowing atmospheric variability studies.

This database is divided in three categories according to the profiles spatial extension:

- 1D profiles database: the profiles included in this database are used over the whole computed scene. The database includes the 6 standard AFRL profiles (US Standard, Midlatitude summer/winter, Subarctic summer/winter and Tropical). User profiles and data obtained by radio-sounding are also easily included, with the help of the GUI and an internal profile generator which extrapolates atmospheric thermodynamic data up to the top of the atmosphere (100 km in MATISSE).
- 2D profiles database: the profiles come from a climatology providing the average thermodynamic profile on each latitude band with a 10° sampling and for 8 seasons of 45 days,
- 3D scenes database: the GUI allows the construction of user 3D scenes. The spatial resolution (in longitude and latitude) is defined by the user, and the atmospheric profiles come from the MATISSE profile database or user profiles. These 3D scenes are used for evaluation of the 3D atmospheric variability.

3D atmospheric radiative transfer computation

One of the characteristics of MATISSE is its ability to take into account atmospheric spatial variability along each LOS. The atmosphere is modeled by a grid, in which thermodynamic parameters (pressure and temperature) and all the computed radiative parameters (atmospheric source functions, local illumination, extinction coefficients, aerosols phase function,…) are stored for each node. Atmospheric spatial variability can then be taken into account, provided that input data are either outputs from weather forecast codes or user-defined 3D scene built with the help of the GUI previously mentioned. For a 3D description of the atmospheric aerosols, MATISSE includes a 5°x5° sampled climatology database with global coverage.

Computation of ground temperatures

Thanks to the MATISSE API mode, the two functions "atmosphereMATISSE" and "temperatureSol" allow one to extract from MATISSE the local atmospheric profile, and the ground temperature plus land use at a given position. The local atmospheric profile contains for each atmospheric layer the following information: pressure, temperature, air density, molecular mixing ratio and relative humidity.

4. FUTURE WORKS

4.1 Computation of the sea surface radiative properties

MATISSE-v2.0 is able to generate irradiance images of the sea surface, taking into account solar glint effects, with a one meter spatial resolution, but also including sub-pixel radiation variability. The requirement to compute images in any observational geometry implies development of a multi-resolution model to generate images in grazing view geometry. In MATISSE, the retained multi-resolution approach is based on the 'geometry clipmaps' method [6]. Thus the sea surface is modeled with facets whose size depends on their distance to the observer. Regarding sea surface radiation, an infrared optical properties model developed for a wind-roughened sea surface gives the analytical expressions of BRDF (Bidirectional Reflectance Distribution Function) and effective emissivity [7,8]. The first-order geometrical-optics approach is used and the surface slope is supposed to be governed by a stationary, ergodic Gaussian process. Effective optical properties are computed for each multi-resolution facet, depending on the facet size, their mean slope, the sun and the observer geometry. These quantities could then be extracted from MATISSE and used in the SE-Workbench code.

4.2 Validation based on MIRAMER measurement campaign

In order to validate the MATISSE-v2.0 sea surface radiance model, a large data collection campaign (MIRAMER [5]) was conducted in May 2008. The main objective of the campaign was to measure sea surface radiances in the infrared band to be compared to the MATISSE simulated radiances. It was also necessary to make environmental measurements along with these radiances measurements, to fill in MATISSE input data.
MIRAMER was divided in two parts: a ground campaign that took place at Saint-Mandrier (France) from 13 to 28 May 2008 and an oceanographic cruise off Saint-Mandrier with the IFREMER (French Research Institute for Exploitation of the Sea) R/V ATALANTE made available thanks to French Navy Oceanographic and Hydrologic Service (SHOM), from 18 to 29 May 2008. For the cruise, bands II and III infrared cameras, the Onera’s bands II and III infrared imaging system Timbre-Poste with very high radiometric and spatial resolutions, and an infrared spectroradiometer were mounted on board the ATALANTE ship along with environmental measurements. As already mentioned, the campaign was devoted to sea surface radiance measurements, but some coastal images have been acquired from Nice to Marseille. These calibrated images could be used to validate the MATISSE /SE-Workbench simulation chain.

4.3 Coupling with weather forecast codes

As already mentioned, MATISSE is able to take into account atmospheric spatial variability along each line of sight forming the image, using weather forecast outputs. In addition, ground temperature is computed depending on local atmospheric conditions, date and location. These two functionalities allow one to predict IR contrast on interest scenes as battlefields for example, providing computations are performed in a time compatible with the short term weather forecast. Nevertheless, in the current version of MATISSE, all the spectroscopic parameters relative to atmospheric profile (MATISSE use a CK model) are computed and stored in a CK parameters database prior to any MATISSE computation. Using MATISSE requires this pre-computation phase, which can be time consuming for extended 3D scenes. In future works, we plan to modify the radiative transfer method to avoid this pre-computation phase; that would allow one to use MATISSE for prediction applications and would give some mission planning capabilities to the SE-Workbench.

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