SPECRAY EM / FERMAT – A NEW MODELLING RADAR APPROACH FROM NUMERICAL MODELS OF TERRAIN TO SAR IMAGES

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1. ABSTRACT

Tools for electromagnetic simulation, such as SPECRAY EM / FERMAT, a jointed development of OKTAL SE company and French ONERA EM research centre, are well adapted to RCS or ISAR image computations down to millimetre wavelength for high realistic targets described using detailed CAD files.

Moreover, this type of tool can be efficiently used in order to compute the same RCS of targets but taking into account the close environment, i.e. the clutter of this target, in the same run.

Besides, it is possible to use the same type of tool in order to compute a complete reflectivity map of the terrain, including targets, that can be a very nice input of SAR treatment models.

The basic problem is the terrain modelling.

OKTAL SE company has developed the AGETIM terrain modelling tool, with the support of ANVAR, DGA and CELAR in France. This tool enables to automatically generate a 3D terrain mesh including complete modelling of features like roads, rivers or forests. This "terrain CAD file" is enhanced with physical attributes at polygon or texture level, which enables to perform EM ray tracing computations in order to provide a virtual stimulus to SAR imagery models.

This paper intends to present the whole process from geographical data to SAR reflectivity map.

2. THE SAR COMPUTATION PROCESS

2.1. Introduction to SPECRAY EM / FERMAT

The SPECRAY EM / FERMAT software is the ray tracing kernel of a complete EM workshop including various tools such terrain and objects modelling tools, texture tools, physical data edition tools, tools for edition of scenarios relating to a given sensor, post-processing and visualisation tools.

The basic function of SPECRAY EM / FERMAT is to deal with the electromagnetic calculations of the interactions between EM wave and the observed scene.

This tool has the ambition to calculate scattered EM fields at high frequencies (i.e. the size of objects is supposed large compared to the wavelength), in a virtual 3 D, geometrical and physical complex environment including natural and man made objects. EM fields calculations either on a surface or in a volume could be carried out according to specific applications.

Figure 1: Examples of natural and man made databases

2.2. General ray tracing characteristic of SPECRAY EM / FERMAT

The SPECRAY EM / FERMAT kernel input is a meshed database made of triangles in order to accelerate the intersections computation. Figure 3 describes the general architecture of this kernel.

The first box represents a so called "voxelisation" algorithm that is implemented in order to be less sensitive to the amount of polygons in the 3D scene. This optimization is compulsory in SAR case, because of the size of the scene we have to deal with and because of the accuracy of representation we need in order to be physically realistic.

The second box concern all the basic mechanisms enabling to cast rays in the 3D space from the SAR. These mechanisms are very sophisticated and self adapt to the local scene complexity. This adaptation is generally called "antialiasing". To perform this antialiasing, adaptatively and lazily (only if necessary), the general physical model has to be taken into consideration for each interaction.

This is a key point of the technical approach and the only way to spare rays and so be able to analyze a whole SAR scene. This approach is radically different from classical asymptotic methods where a first computation of all the possible geometrical path within the scene is made (not affordable on the SAR case due to the scene size and the scene accuracy) and then the application of a physical model.

2.3. EM generalities concerning SPECRAY EM / FERMAT

In the frame of SPECRAY EM / FERMAT, a geometrical Shooting and Bouncing Rays (SBR) technique has been optimised in order to calculate the intersections between rays from the transmitter towards the database and back to a receiving point. EM models of propagation, reflection, diffraction and an operating strategy (thanks to SBR) which allows unified calculation for the near or far EM scattered fields from the scenes. These models are the formulations of Geometrical Optics (GO), Physical Optics (PO), Uniform Theory of Diffraction (UTD) and Equivalent Current Method (ECM). Again, these models, judiciously coupled with the SBR technique make the computation time slightly dependent on the complexity of the treated virtual scene.
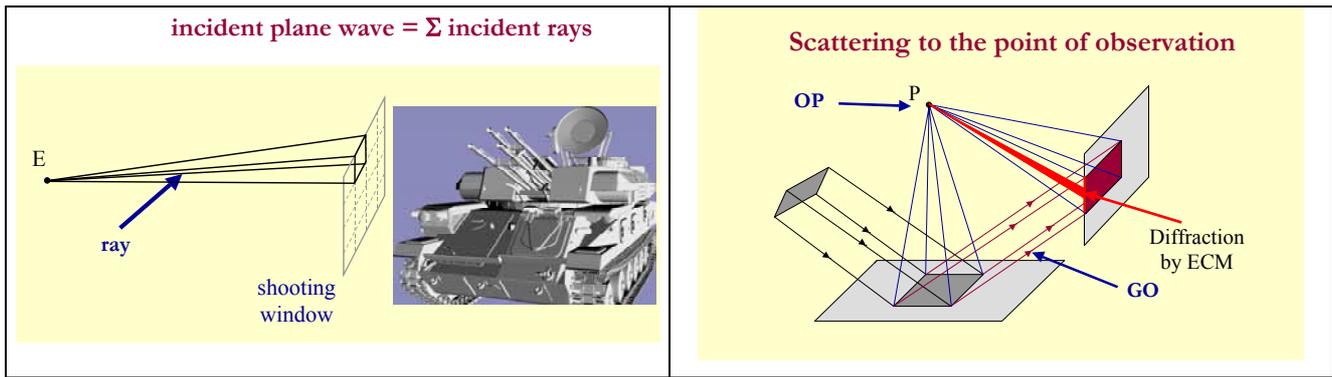
Figure 2: Coupling of SBR technique and EM asymptotic methods

The computation gives for every point of reception the contributing "diffusing points" in the scene. A "diffusing points", for one X, Y, Z location in the scene, is an EM amplitude and phase, for a given wavelength and polarization for emission/reception.
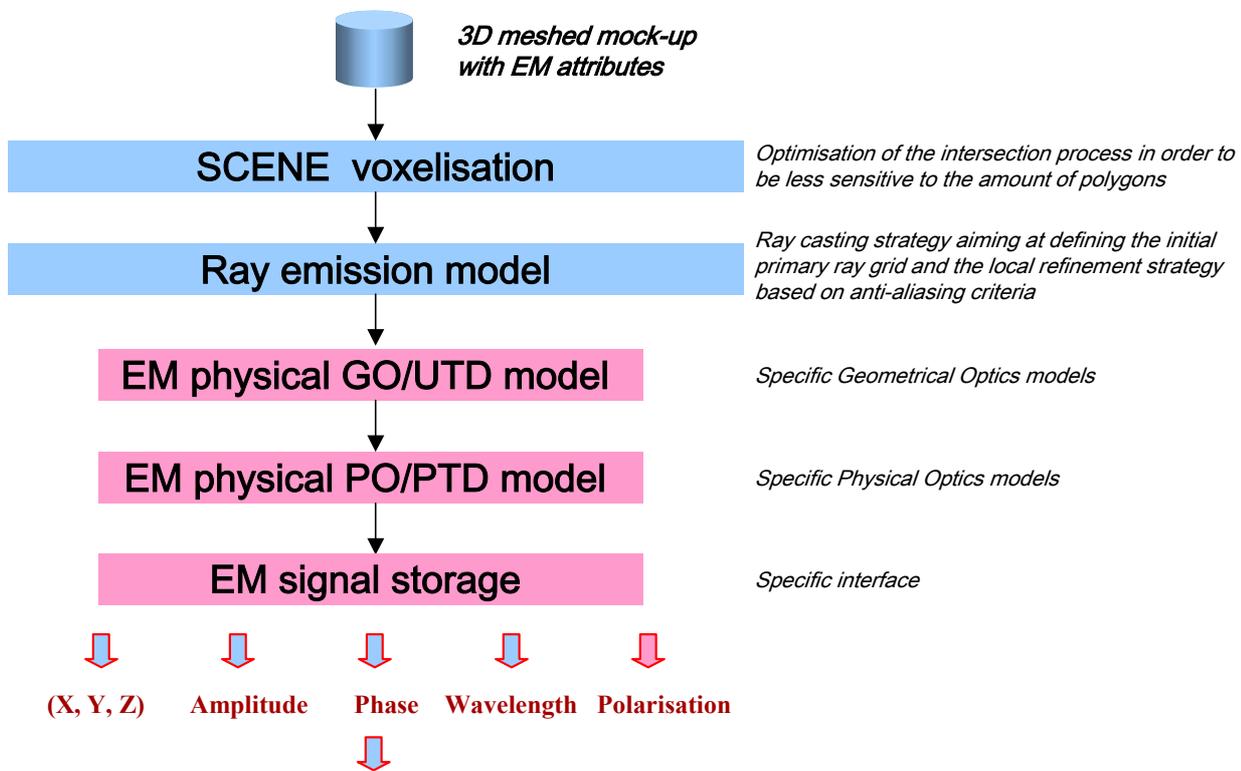

Figure 3: Architecture of SPECRAY EM / FERMAT

2.4. Texture classification

The texture classification is a fundamental operation that is necessary for SAR application for several reasons detailed here after.

In the virtual reality world, a texture is a simple visible picture mapped onto a polygon. A texture identifier and a mapping matrix is attached to each polygon inn order to get a textured scene. The texture classification is a generalization of the classical texture concept applied to physics. The classical texture, made of an array of coloured "texels" (texture elements), is turned into an array of "pointers" of physical material. Each so referenced material contains the required physical data, for instance the Fresnel coefficients for dielectric texels.

The basic texture utility in the frame of classical image synthesis domain can be decomposed in three axis:

- To minimise the amount of polygons in the database: for example, it is much easier to model a house front with one polygon, mapped with a house picture texture, than to use several polygons in order to model the door, the windows and shutters
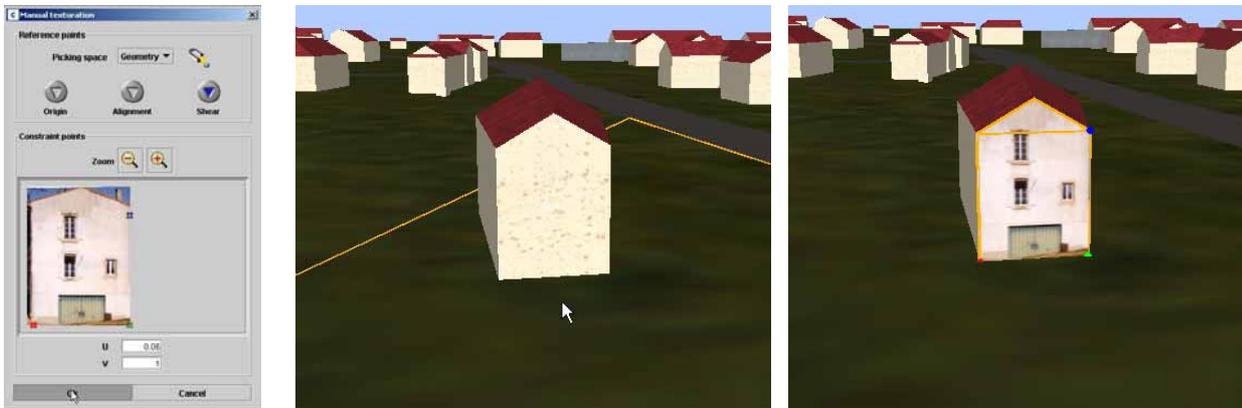

Figure 4: Texture replacing geometry

- To improve the rendering of a database, by inducing modulation ("noise") on polygons (a simple coloured polygon is uniform, and its realism is poor). In the frame of SAR imagery, this axis is fundamental. As a matter of fact, texture enables to fight sampling effects due to simple geometry, for instance abusive straight limits of features (road against neighbouring terrain) that could be incompatible to SAR image processing (because too simple to contouring). Figure 5 and figure 11 illustrate this texture advantage.
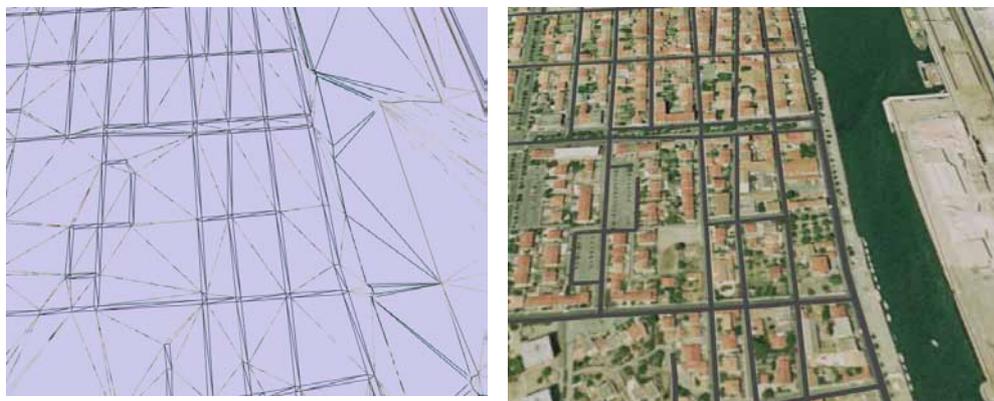

Figure 5: Texture inducing detail and noisy shapes

- To deal with transparencies

Figure 6: Modulation and map of transparency

Texture classification conveys an other very important advantage: obtaining a spatial variety of material even if the shared basic material list is somehow reduced. For instance, even with three different materials, figure 7 shows that a real material diversity of terrain can be easily created.

The EM workbench that encapsulates SPECRAY EM / FERMAT includes the PTT EM tool, an extension of the Adobe Photoshop 2D graphic tool, that enables to classify textures.

Figure 7: Texture classification using PTT EM

2.5. SAR specificities

The SAR reflectivity computation needs a minimum scenario definition that enables to fix the primary grid of rays casting through the 3D scene. The ray emission model adaptatively fits to the 3D and EM complexity. In the case of SAR simulation, transmitter is located in the same position as receiver, which is called the monostatic case. In the same run, SPECRAY_EM/FERMAT computes the targets Radar Cross Sections and the terrain using the radar model supported by range gate definition. As explained before, adaptatively i.e. automatically, the ray tracer invokes either Geometrical Optics for surfaces associated to Unified Theory of Diffraction for edges and Physical Optics for surfaces associated to Physical Theory of Diffraction for edges.

As a result, for the whole scene, EM contributors are computed. Contributors form collection of bright points whose combination produces the reflectivity map of the scene. More precisely, a contributor is made of a 3D position and a complex value of EM field depending on wavelength, dealing with polarization and Doppler.

The SAR modeling can be made easily, which is the main advantage of simulation. In the real SAR, the EM contributors are not known independently. Only the global combination of these contributors is known. Besides, the radar position is neither known very precisely. On the contrary, in simulation, everything is known with perfect accuracy. That is the reason why the model can be simple.

In order to simplify the process, for a first approach, a simplified model has been developed in order to construct a reflectivity map as an input of an external SAR treatment model. In the frame of this simplified domain, the real SAR antenna is replaced by a sharp synthetic antenna imaging one column of range gates for one given position of the SAR carrier. The SAR reflectivity map is then built by aggregation of these columns, which is very efficient in computation time.

With the same tools, we now plan to simulate a large real antenna beam, potentially with secondary lobes, which should be more time consuming and should require a real SAR treatment in order to see an image.

2.6. SAR computation

Practically, the first step is the SAR computation configuration. The GUI enables to define different input parameters:

- Frequency
- Polarisation
- Autocorrelation function
- Squint
- Carrier trajectory
- Antialiasing data

INPUT DATA		
Radar height	hradar	2000
Near distance	L	4000
Far distance	L2	1024
Range gate size	Srg	1
Amount of contributors per range gate	Nc	1
Pixel dimension at far distance	Resolution	1

Automatically, the tool turns these data sensor SPECRAY file (.cpt) with the following information:

COMPUTED DATA		
Blind Zone	d1	4472,1360
Range	d2	5407,4556
Range gate number	Nrg	935,0000
Lower site	S1	-0,4636
Upper site	S2	-0,3789
Vertical aperture	AlphaV	4,8581
Range Gate Horizontal aperture	AlphaH	0,0106
Antenna Site	Sa	-24,1360
Contributor angle	sigma	0,0001
Contributor dimension at far distance	ResC	0,3981686
Minimum antialiasing level	Al	1

This enables to precisely define the SAR carrier trajectories and the antenna beam aiming, including the squint management (angle between the line of sight and the line of movement).
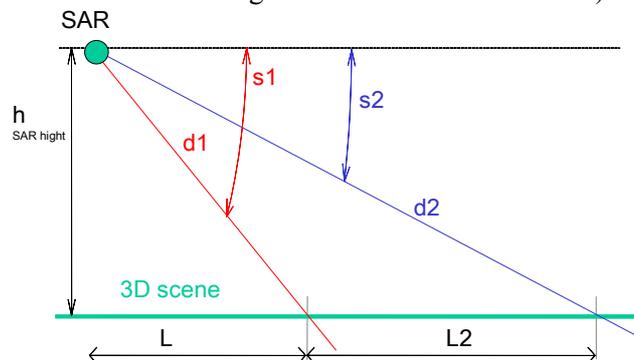

Figure 8: SAR scenario definition

Once parameters have been configured, a special GUI allows to observe the scenario interactively before launching massive ray tracing computations.
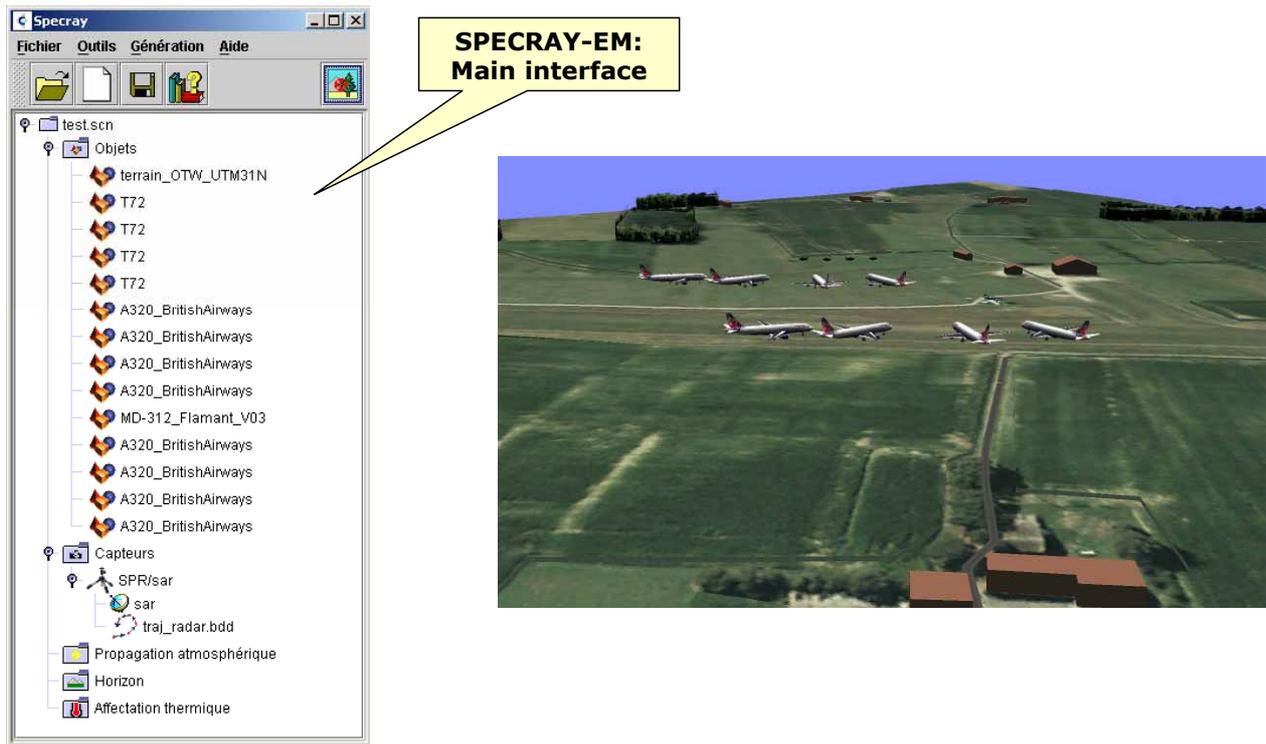
Figure 9: SAR scenario observation

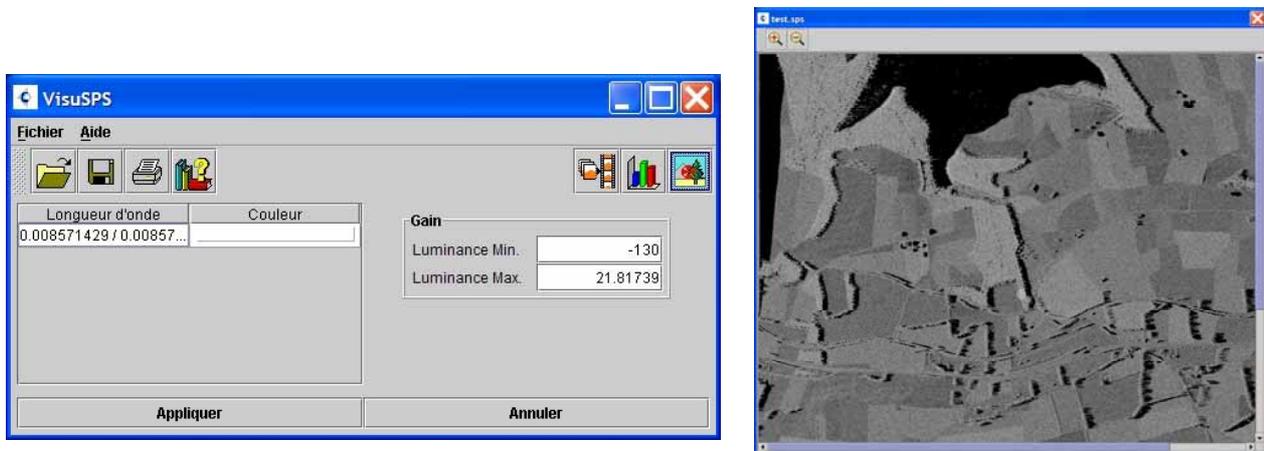Finally, computation can be launched and SAR cartography images visualised and assessed.

Figure 10: SAR image assessment

3. THE TERRAIN MODELLING PROCESS

3.1. Introduction to AGETIM

OKTAL SE company has developed the AGETIM terrain modelling tool, with the support of ANVAR, DGA and CELAR in France. This tool enables to automatically generate a 3D terrain mesh including complete modelling of features like roads, rivers or forests. This "terrain CAD file" is enhanced with physical attributes at polygon or texture level, which enables to perform EM ray tracing computations in order to provide a virtual stimulus to SAR imagery models.

The image below shows the result obtained using AGETIM. In this image, represented in the visible domain, an "ortho photo" has been first geo-referentiated using AGETIM, then turned into a EM classified texture in order to differentiate the physical materials at texel level. Besides, elevation data for terrain and building have been associated using AGETIM in order to render the 3D volumes and corresponding masking effect, which is very necessary for the ray tracing process.

Figure 11: 3D virtual mock up produced by AGETIM

AGETIM product allows a database characterization in parallel to the terrain modeling. This process is based on profiling "templates" (see after) and integrating 3D models that have been previously physically characterized.

For example, during the terrain modeling, roads are created and automatically textured using road templates and the associated road textures. At the same time, the physical properties coming from the road template will be automatically attached to them. At the end of the terrain generation process the virtual 3D scene is ready for a spectral analysis.

3.2. AGETIM architecture

The first stage of AGETIM is made of heterogeneous source data manipulation that can be separated into:
- Elevation data:
    o Terrain grids (DTED, DIGEST, SEDRIS, Alti files)
    o Terrain lines (altimetry maps)
- Feature data (vector information)
    o 2D cartographic data that can be visualized and edited (DFAD, VMAP, Topo files)
    o 3D plans of buildings (DWF)
- Photos (raster information)
    o Satellite images or air-type images that can be imported and integrated into a predefined coordinate system

For this stage, dedicated algorithms exist in order to take care of the data fusion processes, the source data correction methods and the automatic or semi-automatic terrain generation.

AGETIM includes the GEOCONCEPT GIS Graphical User Interface, which enables to do a lot of correction manually. For example, a bad correlation between a feature location and the corresponding elevation can be automatically corrected at the source data level. For instance, it is possible to draw vector data directly on a raster photo information, to enhance the feature data quality and consistency.

The second stage is the preparation of the templates and the objects library, including the preparation of the EM physical attributes.

The first mechanism is simple. It is called instantiation of objects from a shared object library. The general idea is to replace an identification code (in the feature dataset) at source level by a full 3D object at meshed level. For instance, elementary dipoles constituting the ILS can be instantiated.

The second mechanism is more powerful. It is called profiling templates. The general idea is to replace a source level data by a local meshing fitted to the source data. For instance, as shown in the next figure, a section (or profile) of a road is pre defined (that respects the source data information, in this case a two lanes highway), and this section is profiled with respect with both the 2D shape of the road axis and the local terrain elevation.

This template geometrical effect must be associated to an attribution of physical materials. For instance in the EM domain, a physical characterization of the wall for the buildings can be necessary, which leads to a global definition of the "wall" material in term of dielectric Fresnel coefficients, based on a decomposition into multi layered inner materials. And this definition is automatically conveyed by the template profiling.
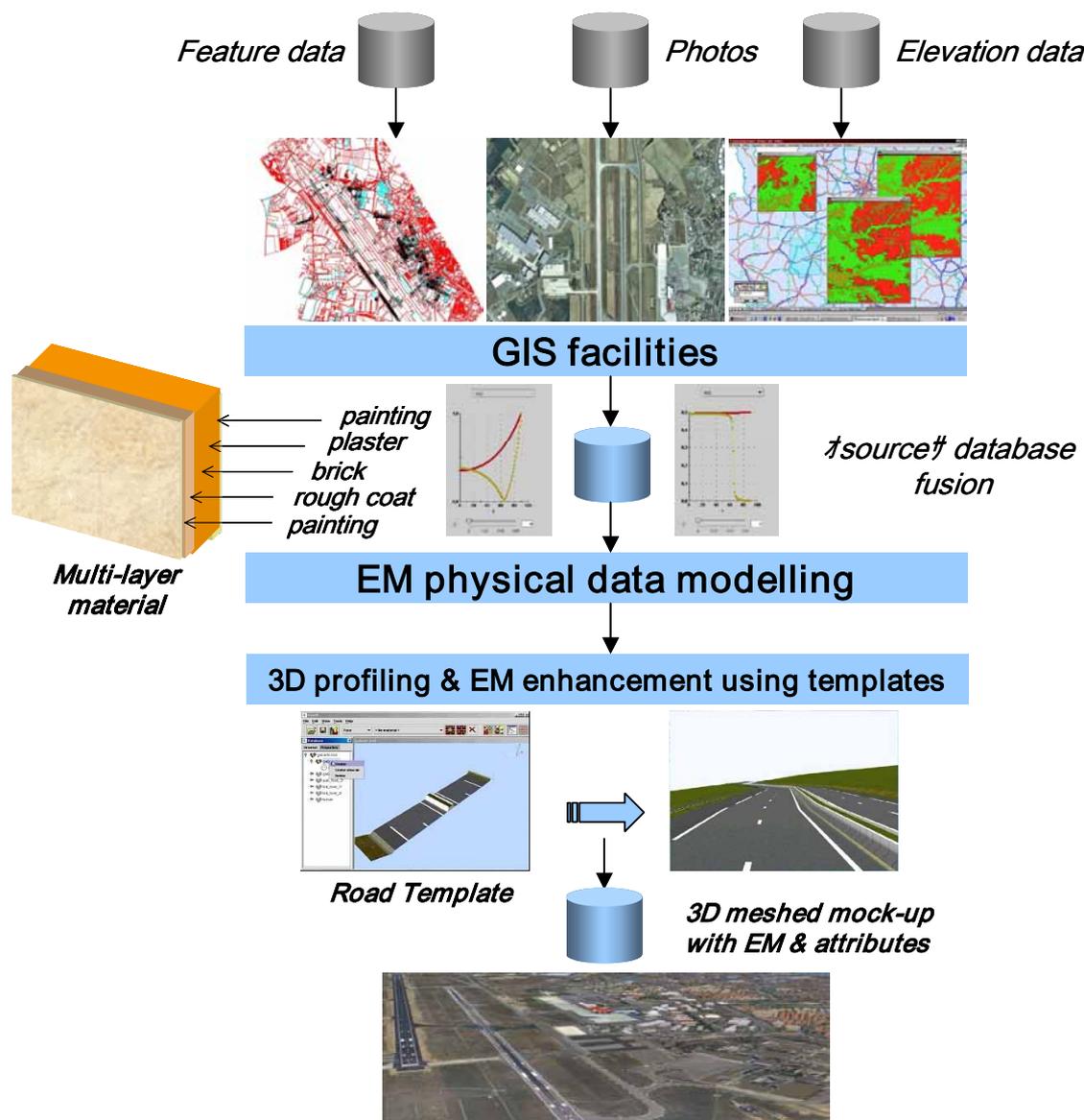

Figure 12: AGETIM architecture

4. FULL EXAMPLE FROM CARTOGRAPHIC DATA TO SAR IMAGE

4.1. Global process

The global objective of this full example is to generate a 3D meshed virtual mock up from a scanned map and an airborne imagery. Using this original process, the database is automatically enhanced with EM physical data coming from a sample library of EM physical data. A SAR like scenario is then defined. A EM cartography is computed using then EM ray tracing process. A SAR like image is generated and compared with the corresponding visible image.

The terrain generation tool is AGETIM. The physical basic materials database and the associated templates are processed using GAIA EM. The physical classification is made using PTT EM. The EM cartography is computed by SPECRAY EM / FERMAT and the SAR image visualised using VISUSPS/SPR2SPS tool.
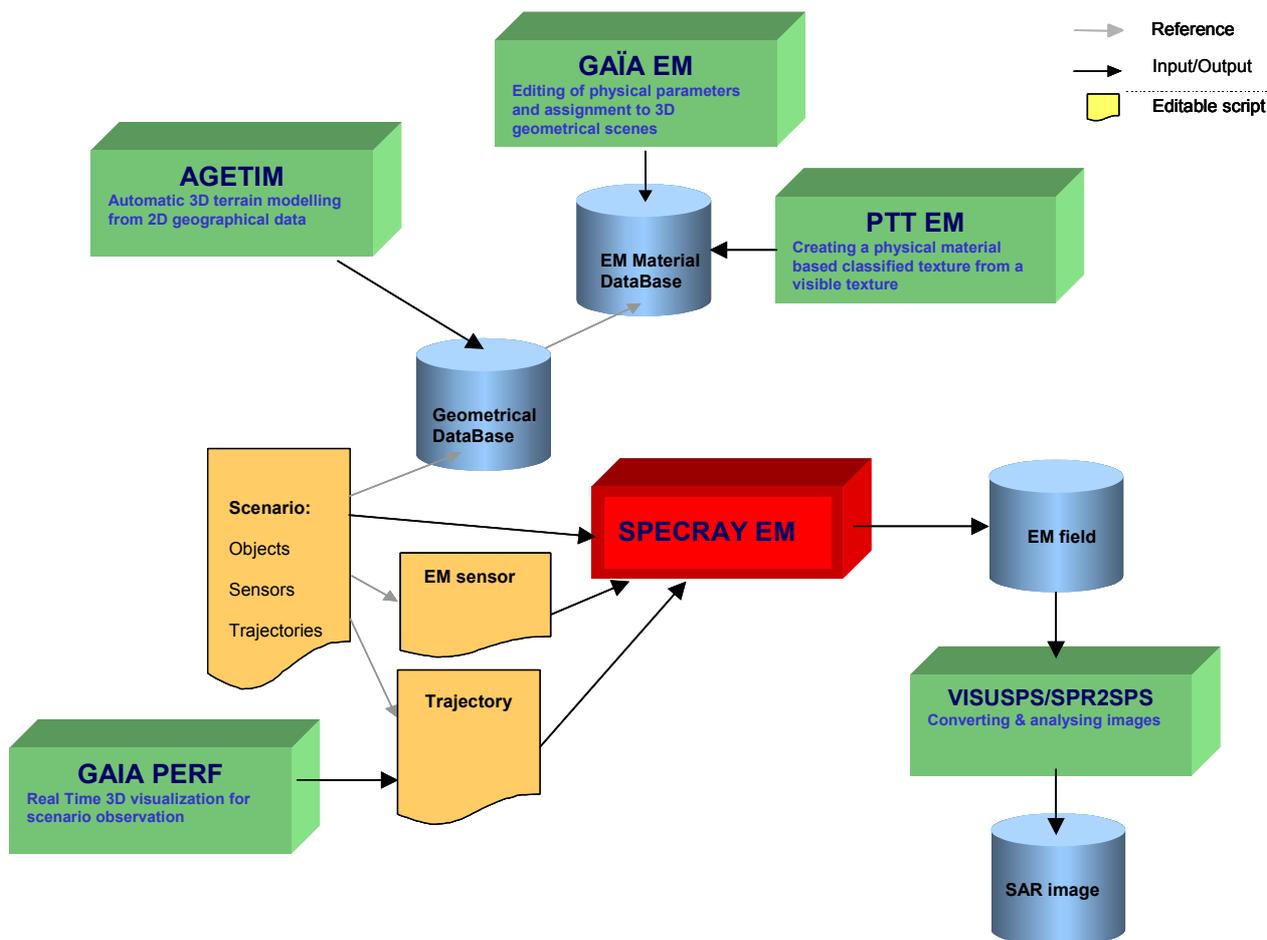

Figure 13: Full example architecture

4.2. Geographical data processing

As shown in the figure below, AGETIM enables to import geographical data corresponding to a south French harbour location. Basically, these data contain a vector information of road axis and footprints of buildings and tanks.
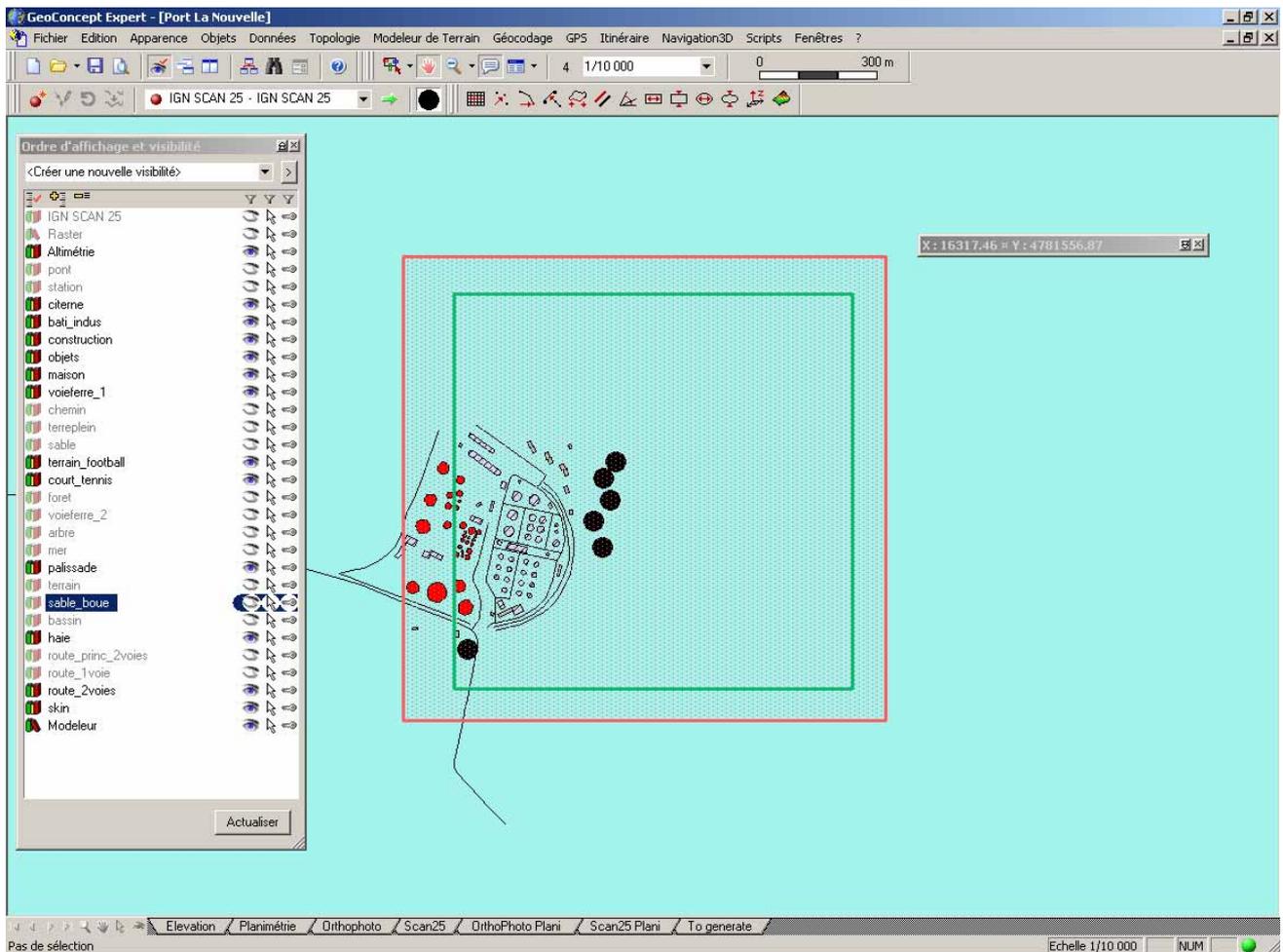
Figure 14: Geographical feature data processing using AGETIM

4.3. 3D virtual mock up creation

Automatically, the 3D corresponding virtual mock up is generated and can be pre visualized interactively using GAIA PERF viewer.

Figure 15: 3D meshed virtual mock up visualization

4.4. Geometrical modification of templates

Using AGETIM it is possible to modify the geometric description of a template and to automatically regenerate de 3D virtual mock up.
For instance, we can replace the template describing the railway track profile, turning automatically a single track in a double track.
The result is shown in the figure below.

Figure 16: Modification of a linear template geometry

4.5. Physical modification of templates

Using GAIA EM and PTT it is possible to modify the physical definition of the texture defining the railway track itself. The texel association can be tuned using PTT EM (left image below) and each EM material physical data can be modified using GAIA EM (right image below).
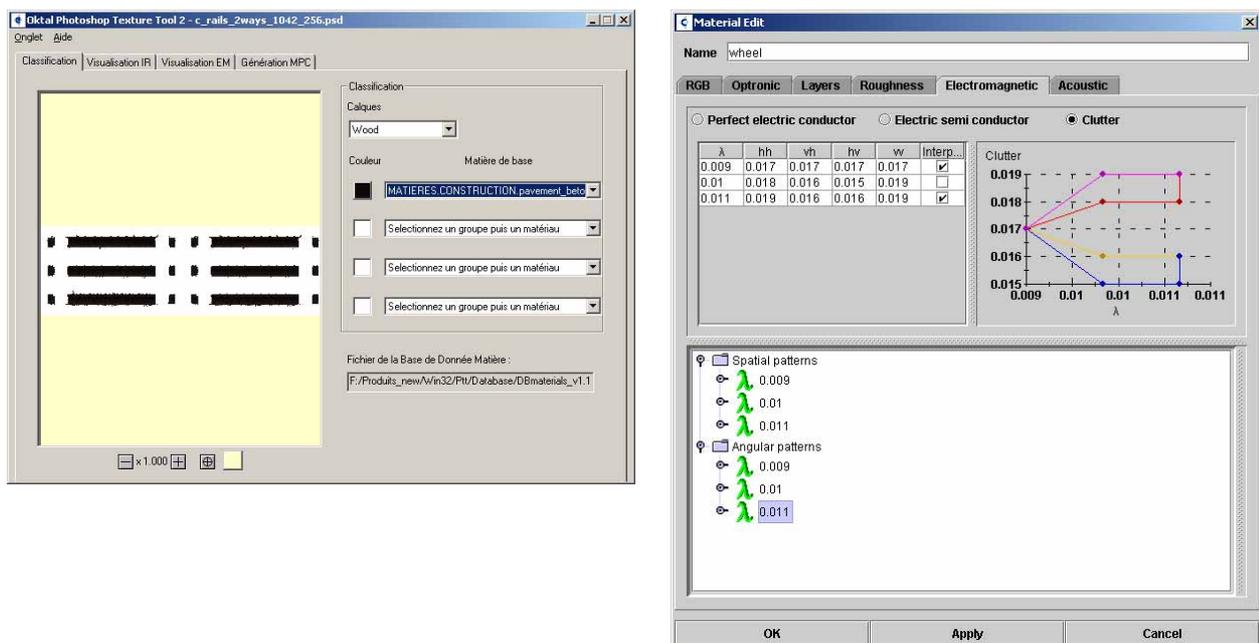

Figure 17: Modification of a linear template radiometry

4.6. SAR computation

Once the 3D database is achieved, a SAR scenario is prepared using the SPECRAY EM / FERMAT GUI in order to compute a SAR image.
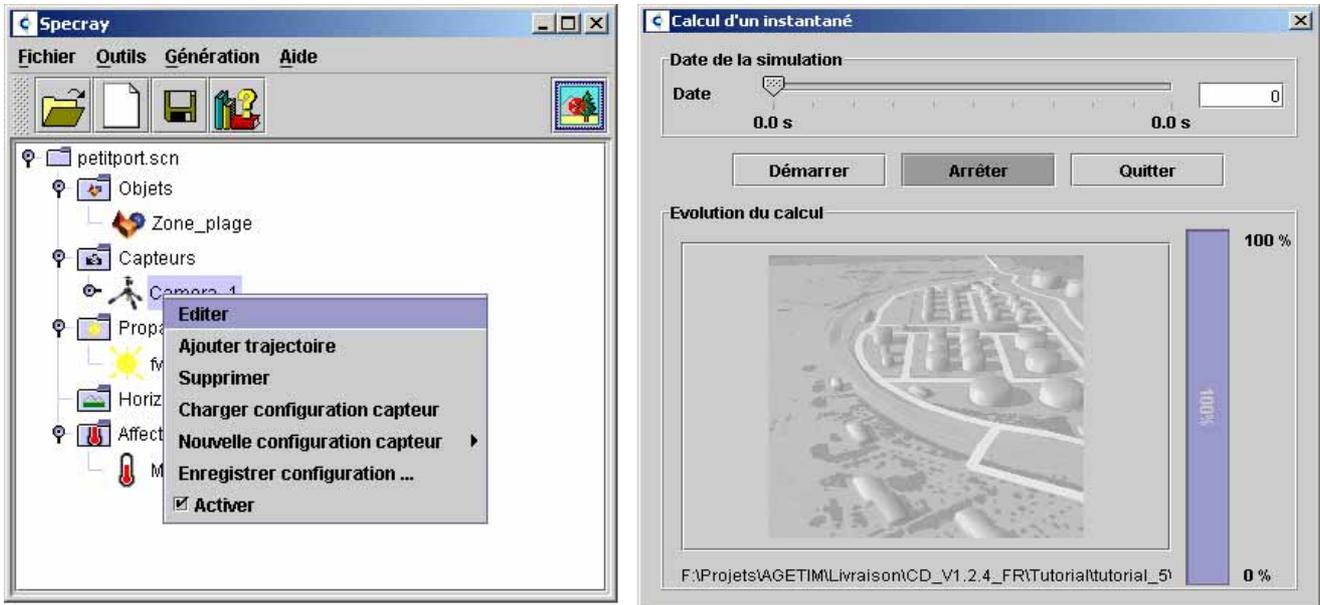

Figure 18: SAR scenario preparation and ray tracing launching

Finally, the SAR image is rendered within some minutes of computation on a basic PC, and can be compared to the equivalent visible image.
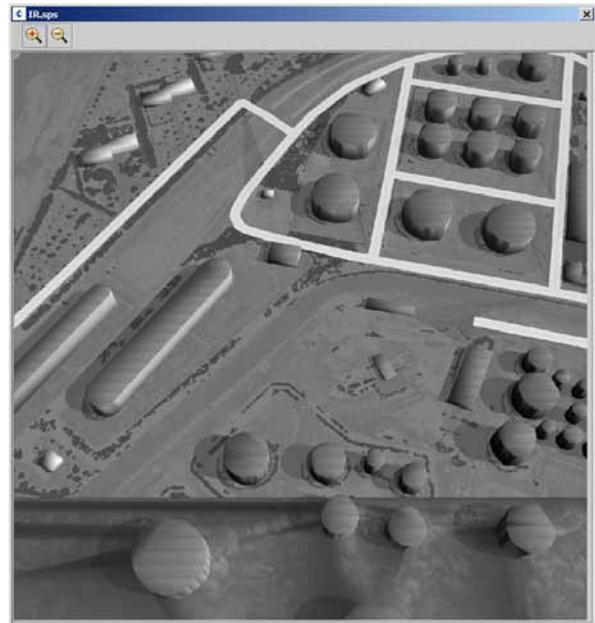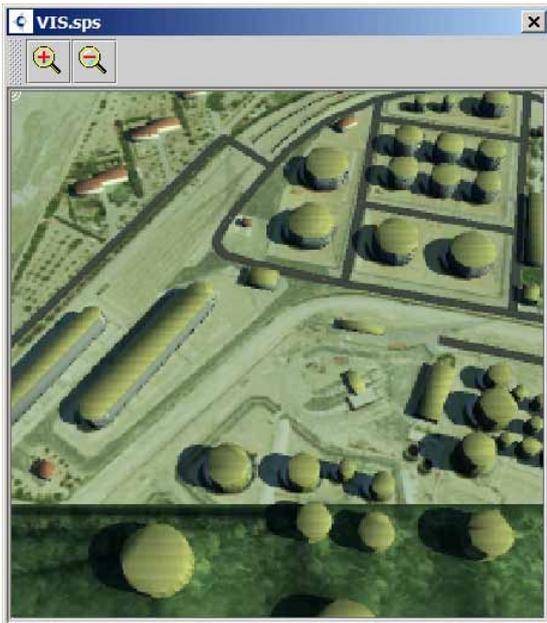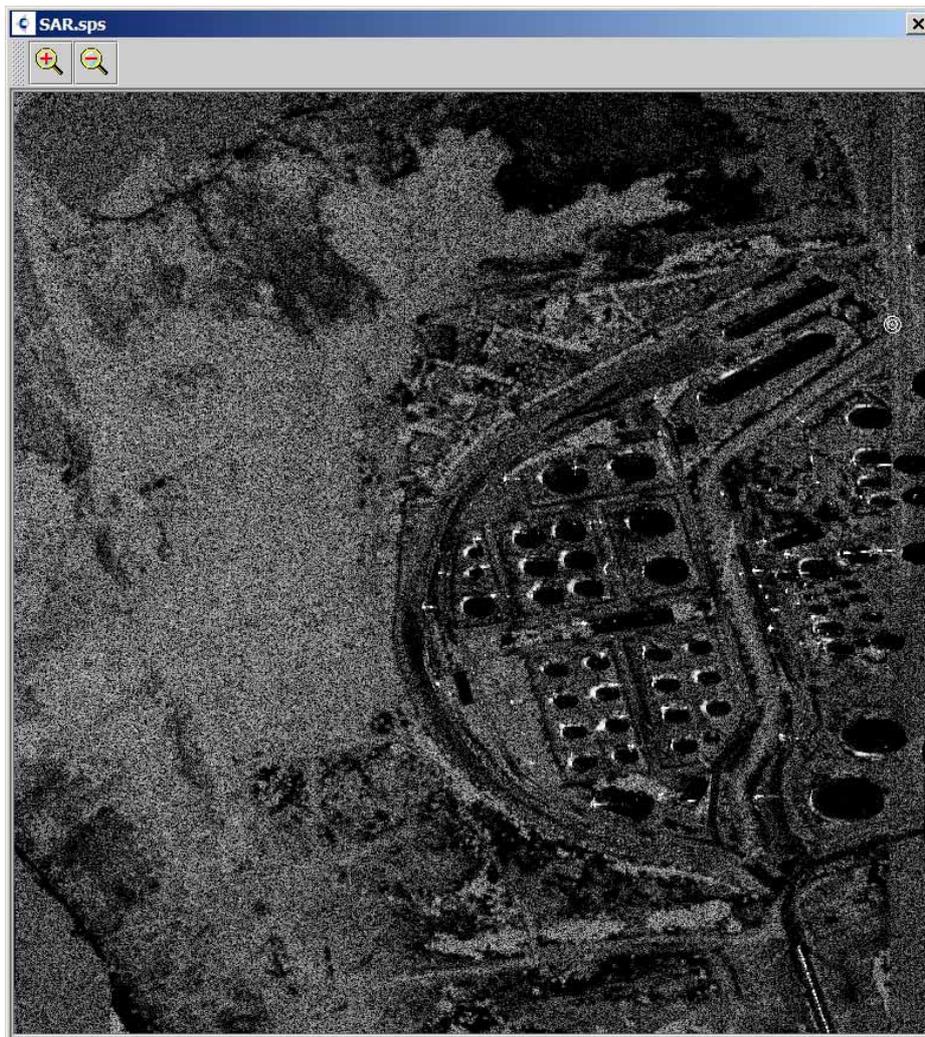
Figure 19: visible & infrared [3,5µm]) image

Figure 20: SAR image (35 GHz)

5. ONGOING WORK - CONCLUSION

The principal shortcoming of this simplified SAR computation of reflectivity map is a generalisation of the method taking into account the real large lobe antenna of a real SAR, in order to couple to existing SAR treatment models.

The correlative action concerns the sophistication of the terrain modelling approach. A lot of improvements are planned for the AGETIM roadmap. On interesting feature is the procedural generation of some classes of objects. Typically, for vegetation, the current release of AGETIM creates a specific geometry (and texture association) for each tree of a detailed forest. This strategy is obviously incompatible with micro-vegetation rendering for instance. In the next release of AGETIM, thanks to a correlative enhancement of SPECRAY EM / FERMAT, micro-vegetation, like shrub and weeds,, will be generated like a procedural 3D texture, without any geometry.

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