European Space Agency
General Study Programme

Statement Of Work

Towards a Generic Radiative Transfer Model for the Earth's Surface-Atmosphere System: ESAS-Light

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1 Introduction

1.1 Scope of the Document

This document describes the activity to be executed and the deliverables required by the European Space Agency in relation to the definition and development of a Generic Radiative Transfer Model for the Earth Surface-Atmosphere System: ESAS-Light

It will be part of the contract and shall serve as an applicable document throughout the execution of the work.

1.2 Background and activity rationale

Radiative transfer modelling creates the link between the remote sensing instrument and the target being observed. As such, radiative transfer tools have a key role in:

- The design remote sensing instruments meeting users / scientific requirements and consequently:
    - Simulate remote sensing instrument observations
    - Perform sensitivity/feasibility/trade-off analysis in mission definition phases
    - Develop future mission end-to-end instrument simulators
- The development and testing of inversion algorithms for the retrieval of geophysical variables (Level 2 algorithms)

The development of a radiative transfer models for the atmosphere-surface system for the optical domain (i.e. from the ultra-violet to the thermal infrared spectrum) has been a matter of continuous concern among the Earth Observation (EO) community and led to several efforts to compile and compare the existing models / radiative transfer methodologies (see Ref 9, Ref 10, Ref 12, Ref 13 or Ref 14). A non-exhaustive list of these radiative transfer models (RTMs) is given in the references (Ref 2, Ref 3, Ref 4, Ref 5, Ref 6, Ref 7, Ref 8, Ref 9, Ref 10, Ref 11, Ref 12, Ref 13, Ref 14). These models differ in their domain of applicability, their overall software architecture and their capabilities. Each model emanates from a different set of original requirements. Whilst Monte Carlo codes applied to a comprehensively described/parameterised environment might provide very accurate numerical solution to radiative transfer problems, they are likely to require important computation resources to be run. Other approaches, based on simplified assumptions of the physics and description of the environment, provide faster results as the expense of degradation in accuracy. Traditionally, during the development of a radiative transfer tool, a trade off is done between the computational speed and the accuracy of the modelling considering its domain of application. A non-exhaustive list of the typical model simplifications or hypothesis follows:

- The polarisation is neglected
- The absorption and scattering processes are assumed to be decoupled
- Gaseous absorption coefficients are integrated over large spectral intervals.
- The atmosphere is considered as a superposition of horizontal layers rather than spherical layers

- Sky noise (scintillation)
- Raman scattering is neglected.
- Etc…

Moreover, at a practical level, when dealing with widely spread RTMs, one runs into the following problems:

- The non-availability of their source code
- Their lack of friendliness of their user graphic interface, if any
- The lack of comprehensive model description documentation
- The limited readability of the code
- The limited validation / verification

Whilst universities and laboratories can only afford to prototype such radiative transfer tools, or develop ad-hoc codes for one-off applications, ESA, in its role of agency in charge of developing space services and applications, will fulfill its mandate by studying the possibility of developing a radiative transfer toolbox including most commonly used forward modeling RT tools and, in the long run, by opening it as a community tool for terrestrial and planetary applications.

1.3 The General Study Programme

The activity specified in this statement of work will be carried out in the frame of the ESA General Studies Programme (GSP) (http://www.esa.int/gsp). The GSP interfaces in different ways with all of ESA's programmes, but its main role is to act as a "think tank", laying the groundwork for the Agency's future activities.
The feasibility studies undertaken by the GSP give the ESA member states and the scientific community the necessary information on which to base their decisions about the implementation of new programmes and the future direction of space activities.
The objectives of the general studies programme are to:

- Contribute to the formulation of the overall ESA strategy
- Study feasibility for selection of new mission concepts
- Prepare/demonstrate the case for approval and funding of new optional projects/programmes
- Support the evolution of ESA by analysing and testing new working methodologies

A diversity of topics is investigated via GSP undertakings, running across the entire spectrum of the agency's activities. Each study usually lasts one to two years, sufficient time for in-depth exploration of each subject.

1.4 Scope and objectives of the activity

In the previous section, the context from which this GSP activity shall emerge was reminded and shall be borne in mind when understanding the scope of this activity. GSP activities are typically exploratory activities enabling ESA to pursue long term objectives. As such, GSP activities are meant to open and pave the way to further work.

The long term objective that this activity shall help to achieve is to give full access to actors in the field of remote sensing of planetary environments to a user friendly, open source, well documented and free of charge radiative transfer toolbox.

Before this long run objective can be met, the first step approach prescribed in the present document is to design a demonstration version of a radiative transfer toolbox, hereafter referred to as the ESAS-Light toolbox, providing modeling capability from the UV to the TIR spectral domain, for the Earth atmosphere-surface system. At completion of this activity, the delivered ESAS-Light demonstration version shall serve a dual objective: a) strengthen ESA modeling capability for internal purposes (instrument design and prototyping of inversion algorithms) and b) provide a set of standard radiative transfer tools for the development of ESA commissioned inversion schemes and calibration/validation activities (for its current and future EO missions). ESAS-Light demonstration version distribution will thus be restricted, in a first phase, to ESA commissioned activities and to internal activities. In the frame of a successive activity (which funding is not yet secured), ESAS-Light could be further improved by expanding its functionalities, imposing higher software quality standards, putting in place a distribution strategy and the web infrastructure to reach the scientific community.

In the light of the previously mentioned contextual information, the objectives of this activity are to:

- Consolidate the set of requirements formulated in the present SoW.
- Develop, validate and document a demonstration version of the radiative transfer toolbox ESAS-Light
- Provide recommendations on the evolution of ESAS-Light capabilities.

1.5 Reference Documents

The following documents can be consulted by the Contractor as they contain relevant information:

Radiative Transfer Theory and Models (non exhaustive list):

Ref 1: Chandrasekar, S, Radiative Transfer, Dover Publication, 1960

Ref 2: Evans, K.F., 1998 SHDOM: The Spherical Harmonics Discrete Ordinate Method for Three-Dimensional Atmospheric Radiative Transfer., JoASs, vol 55, pp429-446.

Ref 3: Vermote, E. F., Tanre, D., Deuze, J. L., Herman, M., and Morcrette, J., 1997, Second simulation of the satellite signal in the solar spectrum, 6S: an overview. IEEE T ransactions on Geoscience and Remote Sensing, 35, 675--686.

Ref 4: Berk A., Anderson G. P., Bernstein L. S., Acharya P. K., Dothe H., Matthew M. W., Adler-Golden S. M., Chetwynd J. H. J., Richtsmeier S. C., Pukall B., Allred C. L., Jeong L. S., Hoke M. L. a., 1999. MODTRAN4 Radiative Transfer Modeling for Atmospheric Correction. SPIE Proceeding on Optical Spectroscopic Techniques and Instrumentation for Atmospheric and Space Research III 3756, 348-353.

Ref 5: Fell F. , Jurgen Fischer, Numerical simulation of the light field in the atmosphere-ocean system using the matrix-operator method, Journal of Quantitative Spectroscopy & Radiative Transfer 69 (2001) 351-388

Ref 6: Anderson, Gail P.; Wang, Jinxue; Hoke, Michael L.; Kneizys, F. X.; Chetwynd, James H.; Rothman, Laurence S.; Kimball, L. M.; McClatchey, Robert A.; Shettle, Eric P.; Clough, Shepard A.; Gallery, William O.; Abreu, Leonard W.; Selby, John E., History of one family of atmospheric radiative transfer codes, Proc. SPIE Vol. 2309, p. 170-183

Ref 7: B. Mayer and A. Kylling. Technical Note: The libRadtran software package for radiative transfer calculations: Description and examples of use. Atmos. Chem. Phys., 5:1855-1877, 2005

Ref 8: Fast and accurate line-by-line radiative transfer model for the infrared: http://www.noveltis.net/4AOP/

Ref 9: Reference forward model of the Oxford University: http://www.atm.ox.ac.uk/RFM/

Intercomparison of Radiative Transfer Models:

More RTM references can be found in the papers listed hereafter.

Intercomparison of RTMs over land surfaces:

Ref 10: B. Pinty, J.-L. Widlowski, M. Taberner, N. Gobron, M. M. Verstraete, M. Disney, F. Gascon, J.-P. Gastellu, L. Jiang, A. Kuusk, P. Lewis, X. Li, W. Ni-Meister, T. Nilson, P. North, W. Qin, L. Su, S. Tang, R. Thompson, W. Verhoef, H. Wang, J. Wang, G. Yan and H. Zang, Radiation Transfer Model Intercomparison (RAMI) exercise: Results from the second phase, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 109, D06210, doi:10.1029/2003JD004252, 2004

Ref 11: Pinty, B., N. Gobron, J.-L. Widlowski, S. A. W. Gerstl, M. M. Verstraete, M. Antunes, C. Bacour, F. Gascon, J.-P. Gastellu, N. Goel, S. Jacquemoud, P. North, W. Qin, R. Thompson, Radiation transfer model intercomparison (RAMI) exercise, J. Geophys. Res., 106(D11), 11937-11956, 10.1029/2000JD900493, 2001

Ref 12: A long list of RT models can be found under the RAMI-3 exercise at http://rami-benchmark.jrc.it/

Intercomparison of RTMs for water

Ref 13: Santer R., J. Fischer , F. Zagolski, D. Ramon, E. Dilligeard, and Ph. Dubuisson , UNCERTAINTIES IN RADIATIVE TRANSFER COMPUTATIONS – CONSEQUENCES ON THE MERIS LEVEL-2 PRODUCTS, Proceeding of the ENVISAT validation workshop 2002

Ref 14: Mobley Curtis, Bernard Gentili, Howard R. Gordon, Zhonghai Jin, George W. Kattawar, André Morel, Phillip Reinersman, Knut Stamnes, and Robert H. Stavn, Comparison of numerical models for computing underwater light fields, APPLIED OPTICS / Vol. 32, No. 36 / 20 December 1993

Intercomparison of 3-D RTMs

Ref 15: Cahalan, R. F., L. Oreopoulos, A. Marshak, K. F. Evans, A. Davis, R. Pincus, K. Yetzer, B. Mayer, R. Davies, T. Ackerman, H. Barker, E. Clothiaux, R. Ellingson, M. Garay, E. Kassianov, S. Kinne, A. Macke, W. OHirok, P. Partain, S. Prigarin, A. Rublev, G. Stephens, F. Szczap, E. Takara, T. Varnai, G. Wen, and T. Zhuravleva, 2005: The International Intercomparison of 3D Radiation Codes (I3RC): Bringing together the most advanced radiative transfer tools for cloudy atmospheres. Bulletin of the American Meteorology Society, Sept 2005.

Miscellaneous

Ref 16: Thuillier, G., M. Hersé, P. C. Simon, D. Labs, H. Mandel, D. Gillotay, and T. Foujols, 2003, "The solar spectral irradiance from 200 to 2400 nm as measured by the SOLSPEC spectrometer from the ATLAS 1-2-3 and EURECA missions, Solar Physics, 214(1): 1-22

Spectroscopic databases:

Ref 17: GEISA: http://ara.lmd.polytechnique.fr/htdocs-public/products/GEISA/HTML-GEISA/index.html

Ref 18: Jacquinet-Husson N., Arié E., Ballard J., Barbe A., Bjoraker G., Bonnet B., Brown L.R., Camy-Peyret C., Champion J.P., Chédin A., Chursin A., Clerbaux C., Duxbury G., Flaud J.M., Fourrié N., Fayt A., Graner G., Gamache R., Goldman A., Golovko Vl., Guelachvili G., Hartmann J.M., Hillico J.C., Hillman J., Lefèvre G., Lellouch E., Mikhailenko S.N., Naumenko O.V., Nemtchinov V., Newnham D.A., Nikitin A., Orphal J., Perrin A., Reuter D.C., Rinsland C.P., Rosenmann L., Rothman L.S., Scott N.A., Selby J., Sinitsa L.N., Sirota J.M., Smith A.M., Smith K.M., Tyuterev Vl.G., Tipping R.H., Urban S., Varanasi P., Weber M. : The 1997 spectroscopic Geisa databank, J. Quant. Spectrosc. Radiat. Transfer, 62, 205-254, 1999

Ref 19: Jacquinet-Husson N., Chédin A., Scott N.A., Chursin V.A.: The GEISA spectroscopic database system revisited for IASI direct radiative transfer modelling, Atmospheric and Oceanic Optics, Vol. 16, No.3, pp 256-282, 2003

Ref 20: HITRAN:http://cfa-www.harvard.edu/HITRAN/

Ref 21: HITRAN'2004 database that was published in a Special Issue of the Journal of Quantitative Spectroscopy and Radiative Transfer, vol. 96, pp. 139-204 (2005)

Miscellaneous:

Ref 22: The BEAM toolbox: http://www.brockmann-consult.de/beam/

Ref 23: Cox, C., Munk, W. Statistics of the sea surface derived from sun glitter , J. Marine Res., 13, pp. 198-227, 1954.

Ref 24: Kliore, A., ed., The Mars Reference Atmosphere. A&. in Space. Res. 2, #2 (1982).

Ref 25: Kliore A. Moroz V.I. Keating G.M. (1986). The Venus International Reference Atmosphere, Pergamon Press, Oxford

Ref 26: Ebuchi, N, Kizu, S, Probability Distribution of Surface Wave Slope Derived Using Sun Glitter Images from Geostationary Meteorological Satellite and Surface Vector Winds from Scatterometers, Journal of Oceanography, Vol. 58, pp. 477 to 486, 2002

1.6 Acronyms and abbreviations

BRDF	Bi-Direction Reflectance Function
EO	Earth Observation
GSP	General Study Programme
HMI	Human Machine Interface
RT	Radiative Transfer
RTM	Radiative Transfer Model
TIR	Thermal Infra Red
UV	Ultra Violet

2 Work to be performed

2.1 Task Description

2.1.1 Task 1: Consolidation of ESAS-Light requirements

The objective of this task is to compile two sets of requirements:

1. A nominal set of requirements for the demonstration version of ESAS-Light delivered as output of the present GSP activity.
2. An extended set of requirements to meet the long term objective behind this activity: the development and distribution of the user friendly, open source, well documented and free of charge radiative transfer toolbox ESAS-Light for the remote sensing community of terrestrial and planetary environments

Prior to compiling these two sets of requirements, the contractor shall carry out a survey of radiative transfer tools and of remote sensing inverse algorithms and associated forward modelling methodologies. Then, on the basis of these surveys and the preliminary set of requirements presented in Annex 1, the Contractor shall compile the two sets of requirements.

2.1.1.1 Task 1.a: Survey of radiative transfer tools

The objective of this task is to survey existing tools / methodologies solving radiative transfer problems. The results of this survey shall be presented in the Survey of radiative transfer tools document.

The Contractor shall compile a list of existing RT tools and models. For each identified radiative transfer tool, he shall provide its main characteristics, namely, as a preliminary, non-exhaustive list:

- The methodology used to solve the radiative transfer equation (Monte Carlo, Successive Orders of Scattering, etc..)
- The spectroscopic database from which the absorption cross sections are extracted
- The spectral resolution of the model
- The methodology associated to the treatment of gaseous absorption (line-by-line, correlated k method, etc…)
- The spectral range over which simulations are possible
- The assumptions behind the description of the terrestrial/planetary environment (1D / 3D, spherical atmosphere vs. plane parallel, number of layers, coupling absorption/scattering, etc…)
- The degree of accessibility and user friendliness of the tool: price, availability from web, licensing policy, documentation status, etc.
- The pros and cons of the tool
- The expected evolution of the tool

A first list can be compiled starting from these references: Ref 2, Ref 3, Ref 4, Ref 5, Ref 6, Ref 7, Ref 8, Ref 9, Ref 10, Ref 11, Ref 12, Ref 13, Ref 14.

A discussion on the methodologies to perform forward simulation (Monte Carlo, Spherical Harmonic Discrete Ordinate Method, Successive Orders of Scattering, etc…) shall be included in the task output document. This discussion shall highlight the main characteristics of these methodologies and their pros and cons (e.g: computational speed, accuracy and complexity to be coded)

A list of potentially computable radiative transfer parameters shall be compiled from the study of the different models, e.g.: radiances, reflectances, brightness temperatures, upward/ downward transmission for each gaseous species, total optical thickness, irradiance at all altitudes, absorption cross sections, atmospheric spherical albedo, etc…

Moreover, as part of this task, the Contractor shall compile a list of existing spectroscopic database relevant to the modelling of absorption in planetary atmospheres (e.g.: Ref 17, Ref 18, Ref 19, Ref 20, Ref 21). The list shall include the main characteristics of these spectroscopic databases, their current limitation (in terms of accuracy, molecular species covered, range of temperature, pressure, density, etc...)

A comprehensive literature review on surface spectro-directional reflective and emissive properties shall be carried out. The Contractor shall include at least the following surfaces in his review: vegetation, snow, water and soil.

Similarly, a literature review of cloud spectral, bi-directional and emissive properties shall be carried out.

A survey of extraterrestrial solar irradiance data (e.g.: Ref 16) shall be performed. Their applicability to ESAS-Light shall be discussed.

Task summary:

- Input:
  - SoW
- Task description
  - Survey of radiative transfer tools
- Output
  - Survey of radiative transfer tools document

2.1.1.2 Task 1.b: Compilation of current and future needs for remote sensing inverse algorithms and associated forward modelling capabilities

The objective of this subtask is to understand what are the current and future needs of the two main users targeted by the ESAS-Light toolbox, namely, ESA in a first step (this GSP activity) and the remote sensing community in a second step (pending on the availability of funding to continue the activity described in this SoW), in terms of forward modelling capabilities.

The Contractor shall compile a list of EO inversion algorithms which development is based on forward modelling methodologies. This list shall cover inversion algorithms for the current and future UV to TIR EO ESA payloads (http://www.esa.int/esaEO/index.html) and by European national space agencies.

As a starting point, the remote sensing inversion algorithms shall be categorised into:

- Land inversion algorithms (e.g. bio-geo-physical vegetation variables retrieval).
- Ocean inversion algorithms (e.g. ocean colour atmospheric correction, sea surface temperature retrieval).
- Atmosphere inversion algorithms (e.g. trace gases retrieval, aerosol retrieval, cloud properties retrieval).

For each one of the identified inversion algorithm, the needs in terms of forward modelling shall be discussed:

- A description of the most appropriate radiative transfer methodologies to perform forward modelling shall be given
- A subsequent list of requirements for ESAS-Light shall be derived

The same exercise of identification of inversion algorithms and associate forward modelling methodologies shall be carried out for planetary environments with emphasis on Mars and Venus environments.

Task summary:

- Input:
    - SoW
- Task description
    - Compile current and future needs for remote sensing inverse algorithms and associated forward modelling capabilities
- Output
    - Needs for current and future forward modelling capabilities for remote sensing document

2.1.1.3 Task 1.c: Consolidation of the nominal set of requirements for the demonstration version of the ESAS-Light toolbox

From the investigations carried out in the previous tasks, the Contractor shall consolidate the preliminary requirements in Annex 1 for the development the demonstration version of the ESAS-Light toolbox. This demonstration version shall provide the main radiative transfer forward modelling capabilities needed to fulfil the long term objective of the ESAS-Light project but the domain of application shall be restricted to terrestrial environments and the UV to the TIR spectral domain (see Annex 1 for more details).

As output of this Task 1.c, an ESAS-Light toolbox requirement document shall compile all identified requirements. These requirements shall be justified by / traceable to the work performed in Task 1.a and Task 1.b and the associated discussions.

The consolidated requirements shall be submitted for approval to the ESA representative prior to the beginning of task 2.

Task summary:

- Input:
  - SoW
  - Survey of of radiative transfer tools
  - Needs for current and future forward modelling capabilities for remote sensing document
  - Preliminary Set of Requirements for ESAS-Light demonstration version (Annex 1)
- Task description
  - Derive requirements for the demonstration version of the ESAS-Light toolbox
- Output
  - ESAS-Light toolbox demonstration version requirements document

2.1.1.4 Task 1.d: Consolidation of requirements for the future evolutions of the ESAS-Light toolbox

An extended set of requirement to meet the long term objective of the ESAS-Light toolbox shall be derived. Particular emphasis shall be put on identifying requirements enabling:

- The extension of the modelling capabilities of the ESAS-Light toolbox
- The extension of the radiative transfer modelling capabilities of the toolbox to planetary environments (in this order of priority): Mars and Venus

- The upgrade of ESAS-Light software to high quality software standards in order to distribute it to a wide community, e.g.: increased code readability, modularity, portability, online help and documentation.
- The distribution of the ESAS-Light toolbox as an open source community software. A particularly inspiring example of such ESA development is the ENVISAT BEAM project. It is a toolbox for the manipulation and visualisation of MERIS, AATSR and ASAR data providing an environment where users' inversion algorithms for these instruments can be plugged in by users who are as well developers (see Ref 22)

The user requirements shall be submitted for approval to the ESA representative prior to the beginning of task 2.

Task summary:

- Input:
    - SoW
    - Survey of radiative transfer tools document
    - Needs for current and future forward modelling capabilities for remote sensing document
    - ESAS-Light toolbox demonstration requirement document
- Task description
    - Derive requirements for the evolution of the ESAS-Light toolbox to pursue the long term objective
- Output
    - ESAS-Light toolbox evolution requirements document (this preliminary version shall be updated at the end of the project as described in 2.1.6)

2.1.2 Task 2: Definition of the ESAS-Light toolbox demonstration version

The objective of this task is to define the ESAS-Light toolbox demonstration version on the basis of the requirements defined in the previous task 1.c.

On the basis of the previously derived ESAS-Light demonstration version document, the contractor shall derive the technical specifications of the toolbox system to be implemented. This work shall be compiled in the Technical Specification document. The specifications of the ESAS-Light toolbox shall be traceable to the requirements identified in task 1.c. A compliance matrix shall be included in the Technical Specification document.

The toolbox system shall be broken down into software components and the contractor shall derive a detailed architecture. This shall also be included in the technical specification document.

The Contractor shall describe in preliminary Algorithm Theoretical Basis Documents (ATBDs) the scientific content of each of the radiative transfer methodologies implemented in ESAS-Light to perform radiative transfer simulations. The preliminary ATBDs shall describe the algorithm in a sufficiently clear and detailed manner to enable the unambiguous coding of these algorithms.

The contractor shall derive a development plan including organization breakdown structure, work breakdown structure, development methods and tools, reused software products, documentation to be produced, risk management, milestones, and deliveries. A first iteration on the development plan, based on the requirements in Annex 1 and those additional identified by the Contractor is expected in the proposal.

Task summary:

- Input:
  - ESAS-Light toolbox demonstration version requirements document
- Task description:
  - Following the consolidated requirements coming from Task 1.c derived a Technical Specification document describing the ESAS-Light system and its architecture.
  - Document in preliminary ATBDs the radiative transfer methodologies to be coded in the demonstration version of the ESAS-Light toolbox
  - Derive development plan for the demonstration version of the ESAS-Light toolbox
- Output
  - Technical Specification document
  - Preliminary ATBDs
  - Development plan
  - Reused existing software source code and binaries (if any) from which ESAS-Light toolbox demonstration version will be built.

2.1.3 Task 3: Coding of the ESAS-Light toolbox demonstration version

The objective of this task is to code ESAS-Light on the basis of the requirements defined in the previous task 1.c.

The Contractor shall develop a demonstration version of ESAS-Light compliant with the list of consolidated requirements compiled in Task 1.c., following the development plan from the previous task and along the lines of the Technical Specification document.

During the coding phase of ESAS-Light demonstration version, an intermediate version of the toolbox shall be delivered prior to a progress meeting. The intermediate version shall implement some of the capabilities of the final toolbox. Such incremental approach shall be reflected in the development plan (output of previous task) and in the verification plan (output of next task).

The final acceptance of all software shall be done at ESTEC, under LINUX and Windows environment. All modules shall be compilable with GNU compilers.

Task summary:

- Input:
  - ESAS-Light toolbox demonstration version requirements document
  - Technical Specification document
  - Preliminary ATBDs
  - Development plan
- Task description:
  - Development the demonstration version of the ESAS-Light toolbox following consolidated requirements coming from Task 1.c, preliminary ATBDs, Technical Specification document and following the development plan
- Output
  - ESAS-Light toolbox demonstration version source code and binary

2.1.4 Task 4: Verification of ESAS-Light demonstration version

The objective of this task is to verify ESAS-Light demonstration version coding and functionalities.

Prior to the coding of the ESAS-Light toolbox demonstration version, the Contractor shall deliver a verification plan in which the procedures to verify the code shall be described. This verification plan shall include verification procedures to apply to two intermediary versions of the ESAS-Light toolbox

Besides the verification of the code per se and its ability to perform as expected, the toolbox functionalities shall also be verified against:

- Other radiative transfer models ran with identical input parameters (e.g.: Ref 2, Ref 3, Ref 4, Ref 5)
- Analytical solutions to radiative transfer problems (see for instance Ref 1 for examples of RT problems with analytical solutions)

- Comparisons between the various methodologies implemented in ESAS-Light toolbox to solve radiative transfer problems. For at least 20 observational test cases over ocean and land surface covering a variety of atmospheric and surface conditions, observational geometries and spectral domains, the various possible methodologies to simulate top-of-atmosphere signals will be compared. As an example of what is here meant, a Monte Carlo simulation could be compared to a fast vector code simulation and a fast scalar code simulation for a purely molecular atmosphere and a totally absorbing underlying surface. The objective of this comparison is to ensure the internal consistency of the demonstration version of the toolbox.

Task summary:

- Input:
  - SoW
- Task description
  - Verify ESAS-Light against existing RT models, analytical solution to RT problems and ensure internal consistency of the various methodologies implemented to simulate space observation.
- Output
  - ESAS-Light demonstration version verification plan (to be issued prior to end of coding phase)
  - ESAS-Light demonstration version verification report

2.1.5 Task 5: Documentation of ESAS-Light demonstration version

The user's manual shall contain installation instructions and operation instructions. Particular emphasis shall be put in describing all input parameters to the modules composing the ESAS-Light toolbox and enabling the parameterisation of simulations.

The contractor shall update the ATBDs. From these, he shall generate a technical note aiming at users and describing the ESAS-Light demonstration version functionalities and scientific content.

Task summary:

- Input
  - SoW
  - ESAS-Light toolbox requirements document
  - ESAS-Light toolbox demonstration software
  - Preliminary ATBDs

  - Technical Specification document
- Task description
  - Update ATBDs and a users manual
  - Generate users manual and technical note.
- Output
  - Final ATBDs
  - Technical note
  - Users manual

2.1.6 Task 6: Recommendation for the future evolution of ESAS-Light

As mentioned in the section 1.4, the long term objective behind ESAS-Light is to provide the remote sensing community with a radiative transfer toolbox enabling forward simulation of the transfer of light in planetary environments. Such long term has substantial implication on the work which will remain to be done once ESAS-Light will be delivered at the end of this GSP activity. In particular, prior to be made widely available, the code behind the toolbox will have to be compliant with high quality software standard (e.g.:ESA ECSS E-40). Moreover, ESAS-Light being intended as a community tool, it is anticipated that an open source approach will be best suited to ensure easy manipulation of the toolbox by users. The open source approach implies that the executable and source code are downloadable from an internet site with the related documentation and an environment/forum for developer willing to contribute by providing new modules to be integrated in the toolbox.

As a consequence of this long term objective and on the basis of requirements identified in task 1.d, the Contractor shall:

- Identify new functionalities for ESAS-Light and estimate the efforts required for their implementation
- Assess the complementarities between radiative transfer tools used for Earth observation and for planetary exploration.
- Estimate the efforts required to extend the scope of the toolbox to other planetary atmospheres
- Identify the existing possible solutions to comply with the open source requirement
- Define strategies to promote and distribute ESAS-Light in the remote sensing community

Task summary:

- Input:
  - ESAS-Light toolbox evolution requirements document

- All previous deliverables

- Task description
    - Propose recommendation to pursue long term objective of the ESAS-Light toolbox
- Output
    - Recommendations for ESAS-Light toolbox evolution

3 Requirements for Management, Reporting, Meetings and Deliverables

The standard requirements for Management, Reporting, Meetings and Deliverables (Appendix 2 to the Contract) shall apply, taking account of the following specific requirements for the present activity, which shall prevail in case of conflict.

3.1 Management

Section 1 of the standard requirements for Management, Reporting, Meetings and Deliverables shall apply.

3.2 Reporting

Section 2 of the standard requirements for Management, Reporting, Meetings and Deliverables shall apply.

3.3 Meetings

Section 3 of the standard requirements for Management, Reporting, Meetings and Deliverables shall apply.

3.4 Deliverables

Section 4 of the standard requirements for Management, Reporting, Meetings and Deliverables shall apply, in particular, the Contract shall deliver together with the final report an executive summary and an abstract.

As indicated in the standard requirements for Management, Reporting, Meetings and Deliverables, the Contractor shall set up a website where the main characteristics of the project shall be described. The content of the website shall be reviewed by the ESA representative prior to its publication. A dedicated a domain name shall be proposed to the ESA representative and shall explicitly contain the name ESAS-Light.

The contractor shall set up a ftp site where all deliverables of this activity shall be upload and continuously updated along the duration of the contract. In addition to all deliverables, the electronic presentation material from progress meetings shall also be stored on this ftp site.

3.4.1 Documentation

Document identifier	Title	Milestone	Number of copies
D1	Survey of radiative transfer tools document	KO+3	1 electronic copy on ftp
D2	Needs for current and future forward modelling capabilities for remote sensing document	KO+3	1 electronic copy on ftp
D3	ESAS-Light toolbox demonstration version requirement document	KO+3	1 electronic copy on ftp
D4	ESAS-Light toolbox evolution requirements document	KO+3	1 electronic copy on ftp
D5	Technical Specification document	KO+6	1 electronic copy on ftp
D6	Development plan	KO+6	1 electronic copy on ftp
D7	Reused existing software source code and binaries (if any) from which ESAS-Light toolbox demonstration version will be built.	KO+6	1 electronic copy on ftp
D8	Preliminary ATBDs	KO+6	1 electronic copy on ftp
D9	ESAS-Light demonstration version verification plan	KO+9	1 electronic copy on ftp
D10	ESAS-Light demonstration version verification report	KO+18	1 electronic copy on ftp
D11	Final ATBDs	KO+21	1 electronic copy on ftp
D12	Users manual	KO+21	1 electronic copy on ftp
D13	Technical note	KO+21	1 electronic copy on ftp
D14	Project webpage	KO+21	1 electronic copy on ftp
D15	Recommendations for ESAS-Light toolbox evolution	KO+24	1 electronic copy on ftp
D16	Final report	KO+24	1 electronic copy on ftp
D17	Executive summary	KO+24	1 electronic copy on ftp
D18	Abstract	KO+24	1 electronic copy on ftp

In addition to the electronic delivery on an ftp server of each deliverable,the contractor shall provide 7 copies of all deliverables of the activity on CDROM (including software hereafter listed).

3.4.2 Software

Item identifier	**Description**	**Milestone**	**Number of copies**
SW1	ESAS-Light toolbox demonstration version (v1)	KO+15	1 electronic copy on ftp
SW2	ESAS-Light toolbox demonstration version (final)	KO+21	1 electronic copy on ftp

For all software developed in the frame of this contract, the source code and binary shall be provided to ESA.

The right to issue sub-licences to reuse the software (binary only) in ESA commission activities shall be given to ESA.

4 Schedule and Milestones

4.1 Duration

The duration of the work shall not exceed 24 months from kick-off to end of the activity (delivery of final report).

4.2 Milestones

The following milestones are suggested:
KO+3 : End of Task 1: Consolidation of ESAS-Light requirements
KO+6 : End of Task 2: Definition of the ESAS-Light toolbox demonstration version
KO+18: End of Task 3: Coding of the ESAS-Light toolbox demonstration version
KO+21: End of Task 4: Verification of ESAS-Light demonstration version
KO+21: End of Task 5: Documentation of ESAS-Light demonstration version
KO+24: End of Task 6: Recommendation for the future evolution of ESAS-Light

The Contractor shall include in the timeline the delivery of an intermediate versions of the ESAS-Light toolbox demonstration version.

The Contractor might propose alternative milestones.

5 Annexes

A.1 Preliminary Set of Requirements for ESAS-Light demonstration version

1 General Requirements

ESAS-LIGHT should be seen as a toolbox: it will not provide a single solution to all possible radiative transfer problems but rather a range of tools which can be applied to specific problems. The long term objective behind this GSP activity cannot be met within the resources allocated because it requires significant effort to define the ESAS-Light requirements, prototype it, document it in a demonstration version. However, such long term objective shall be borne in mind at all stage of the project.

Here follows a preliminary list of requirements for ESAS-Light demonstration version to be consolidated during the first task of the activity:

Req 1-1: ESAS-Light demonstration version shall provide forward modeling capabilities for the Earth's Surface-Atmosphere System for the sun light and Earth emitted light

Req 1-2: ESAS-Light demonstration version shall enable simulations in the spectral interval ranging from the UV to the TIR: from at least 0.2 micron to 50 micron. The underlying requirement is that ESAS-Light demonstration version shall enable to simulate the observations of passive instruments looking at the Earth. Furthermore, by TIR, it is meant that ESAS-LIGHT demonstration version shall be able to simulate most of the emission spectral curve of the coolest terrestrial objects visible from space (e.g: high altitude cirrus, snow/ice fields, etc…)

Req 1-3: ESAS-Light demonstration version shall enable radiative transfer simulations in the Earth atmosphere-surface system with various degrees of precision and computational speed. For each module of the toolbox enabling such forward simulation, the precision of the computation shall be adjustable (e.g.: in the Monte Carlo module, the number of shot photons (if this concept is applicable) shall be an input parameter).

Req 1-4: ESAS-Light demonstration version shall enable simulations of land and ocean surfaces.

Req 1-5: ESAS-Light demonstration version shall enable simulations clouds at various altitudes and of various types.

Req 1-6: ESAS-Light demonstration version shall operate on PC systems under UNIX (SUN), Windows, LINUX and MAC.

Req 1-7: ESAS-Light demonstration version shall be coded in a language that can be run at no cost (no license required).

Req 1-8: ESAS-Light demonstration version shall be coded in a widely used language(s) (e.g.: Fortran, C, Java, etc..).

Req 1-9: ESAS-Light shall be designed in a modular fashion enabling easy implementation of new modules

Req 1-10: An ESAS-Light user shall be able to select among three sources of illumination: the sun, the moon and a monochromatic source of adjustable intensity.

2 Functional Requirements

Methodologies to solve the radiative transfer of light in the Earth atmosphere-surface system

Req 2-1: The ESAS-Light toolbox shall provide at least the following methodologies to perform radiative transfer simulation in the Earth atmosphere-surface system:

- Monte Carlo methodology including polarisation
- Fast vector code enabling resolution of the radiative transfer equation
- Fast scalar code enabling resolution of the radiative transfer equation

Req 2-2: The ESAS-Light toolbox shall provide at least the following methodologies to compute the absorption cross section by atmospheric gases:

- Line-by-line computation
- Correlated k computation

Req 2-3: A user shall be able to solve his radiative transfer problem with any of the combinations of methodologies mentioned in Req 2-1 and Req 2-2. This requirement is meant the enable users to choose the approach that best suits their forward modeling constraints. A user should be able for instance to compute top-of-atmosphere radiances either with a Monte Carlo and line-by-line computation or with a scalar resolution of the radiative transfer equation and correlated k coefficients.

Req 2-4: The ESAS-Light toolbox shall enable users to perform monochromatic simulation at a user defined wavelength. It shall also enable simulations to be performed over a user-defined spectral interval.

Req 2-5: ESAS-Light shall enable simulations of the Raman scattering

Req 2-6: ESAS-Light shall enable simulations of the coupling between scattering and absorption

Req 2-7: ESAS-Light shall enable the simulation of refraction through the atmosphere

Description of the Earth atmosphere-surface system

Req 2-8: ESAS-Light demonstration version shall enable the simulation of the interactions of light with mono dimensional environments where the clouds are modeled as homogeneous layers and the surfaces simple flat surfaces.

Req 2-9: ESAS-Light shall enable the simulation of the interaction of light with water bodies in the VIS-NIR spectral domain. These water spectral and bi-directional properties shall be parameterized by (a) bio-optical model(s)

Req 2-10: The water-air interface reflectance model shall be parameterizable by the two models described in Ref 23 and Ref 26

Req 2-11: ESAS-Light shall enable the simulation of the interaction of light with the water surfaces in the IR spectral domain and particularly in the TIR in order to enable simulation of top of atmosphere brightness temperatures.

Req 2-12: ESAS-Light shall enable the simulation of the interaction of light with snow and ice

Req 2-13: ESAS-Light shall enable the simulation of the interaction of light with a variety of flat land surfaces, which spectral and directional properties can be parameterized. The surfaces modelled shall include the following types:

- Vegetation
- Snow / Ice
- Urban surfaces
- Bare soils

Req 2-14: The library compiling surface spectral and directional properties from the previous requirement shall be expandable by user defined spectral and directional surface properties.

Req 2-15: ESAS-Light shall enable the simulation of the interaction of light with various predefined clear sky atmospheres representative of the latitudinal variations of molecular scale height, aerosol vertical distribution, aerosol types, water vapour vertical distribution, trace gases vertical distribution.

Req 2-16: ESAS-Light shall enable users to perform a simulation with user-defined atmosphere-surface system. The users shall be able to modify, at least:

- Atmospheric gases concentration and vertical distribution
- Aerosol type, optical thickness and vertical distribution
- Aerosol scattering phase function and single scattering albedo

- Altitude of target and altitude at which radiative transfer parameters shall be output.
- Molecular scatterers scattering phase function, optical depth and vertical distribution, depolarization factor, etc…
- Pressure, temperature profiles
- Cloud height, vertical distribution, cloud particle scattering phase function and optical thickness, etc…
- Surface reflective/emission properties pending on the surface type: BRDF, spectral reflectance, etc…
- Geometry of observation
- Geometry of illumination

Req 2-17: If applicable, the number of layers in which the atmosphere is subdivided when performing radiative transfer simulation shall be modifiable by the user.

Req 2-18: ESAS-Light shall enable simulations in spherical atmospheres to be performed.

Simulated output

Req 2-19: ESAS-Light shall output monochromatic or spectrally integrated of at least:
- Radiances / reflectances / brightness temperature at any height within the atmosphere (from surface to top-of-atmosphere)
- Atmospheric scattering albedo
- Solar irradiance
- Upwards and downwards total direct/diffuse transmissions of various gaseous components

3 Human Machine Interface (HMI) Requirements

Req 3-1: Users shall be able to run ESAS-Light from a HMI or in batch mode.

Input / Output data display

Req 3-2: The HMI shall enable the user to enter all parameters of a simulation

Req 3-3: The HMI shall enable the user to visualize the following inputs to simulations:
- Aerosol and molecules scattering phases functions
- Atmospheric temperature profiles
- Atmospheric gases density and cross-sections profiles
- Surface BRDF via polar diagrams

Req 3-4: ESAS-Light shall provide the user with a summary spreadsheet displaying the inputs and outputs of the simulation carried out.

Req 3-5: The HMI shall enable the user to visualize the following outputs of simulations (when applicable):

- Radiance / reflectance / brightness temperature spectrum at any user defined altitude (from surface to top-of-atmosphere)
- Spectral atmospheric transmission of single gaseous component
- Surface and top-of-atmosphere BRDF via polar diagrams

4 Help requirement

Req 4-1: The ESAS-Light toolbox shall have an online help, accessible from a menu item or as a text document describing all the toolbox functions. Each functionality of the toolbox shall be explained. The input and output parameters modifiable by the users shall be clearly listed and their role explained.

Req 4-2: The online help shall be structured in content and index. It shall be searchable via a keyword search tool.

Req 4-3: The readability of the code shall be optimised. All routines shall start with a header describing what the routine does, its inputs, its outputs, how to use it, who has written the routine, when it has been written and other useful information. All routines shall be commented in detail.

Req 4-4: The toolbox shall have a tutorial for developer users, accessible from the HMI, describing the architecture of the toolbox, how to plug in new functions and how to make modifications to the code.