EOMODEL: A MODEL LIBRARY FOR EARTH OBSERVATION END-TO-END SIMULATORS

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ABSTRACT

The development of end-to-end mission performance simulators for Earth Observation missions has been progressively increasing in the last years, with ESA carrying out several activities to promote reuse among end-to-end simulators and reducing the re-engineering process taking place when evolving the simulators beyond the feasibility studies. Two of these activities are the ARCHEO-E2E study and the recently started EOMODEL/BIBLOS activity.

During the ARCHEO-E2E study, an extensive review of Earth Observation missions and their instruments allowed deriving a Reference Architecture for end-to-end mission performance simulators. The use of this Reference Architecture for the development of new simulators has the potential of reducing the reengineering process associated to the evolution of the simulator throughout the different mission phases. Moreover, the identification of common elements for different types of instruments also enables reuse of the architectural elements across several mission simulators. The final task performed in the ARCHEO-E2E activity was the definition of a roadmap to reach an operational Reference Architecture, including the identification of priorities in implementing generic building blocks and improvements to the existing simulation framework and model repository.

The EOMODEL activity builds upon the ARCHEO-E2E project to consolidate its results and implement a selection of some of the modules identified therein. Thus, the objectives of EOMODEL/BIBLOS are the following:
- To identify all the generic models that would need to be implemented as part of an Earth Observation library to be used for the development of mission performance end-to-end simulators.
- To perform the detailed definition, development and validation of a subset of these models, giving priority to those needed to simulate representative satellite images (i.e. Geometry, Scene and Instrument modules).
- To develop a website (BIBLOS) to make the implemented models available to the space community.

This presents the EOMODEL/BIBLOS activity, and in particular the Earth Observation library roadmap and the rationale for the selection of a subset of modules, the models selected for implementation and the type of missions they are applicable to, and the functionality of the library's website.

The EOMODEL/BIBLOS activity is carried out under ESA contract by GMV Poland with consultancy from the Warsaw Military University of Technology.

INTRODUCTION

The EOMODEL/BIBLOS activity is a follow-up of the ARCHEO-E2E project [1], which identified a reference architecture that could be used for developing End-to-end simulators (E2ES) for Earth Observation (EO) missions, as well as the modules and building blocks that compose the proposed Reference Architecture.

The ARCHEO-E2E study focused on the four main types of instruments for Earth Observation. There are 4 main types of instruments: Passive Opticals, Active Microwaves, Passive Microwaves and Active Opticals, [2]. The simulation chain of any E2ES for EO missions can be divided into six high-level Modules: Geometry, Scene Generator, Instrument, Level-1 Processing, Level-2 Retrieval and Performance Evaluation. Although the data flows between these high-level modules and even their order of execution could vary depending on the type of mission and instrument at which they are applied to, Fig. 1 shows the typical generic data flow that is considered as the Reference Architecture.
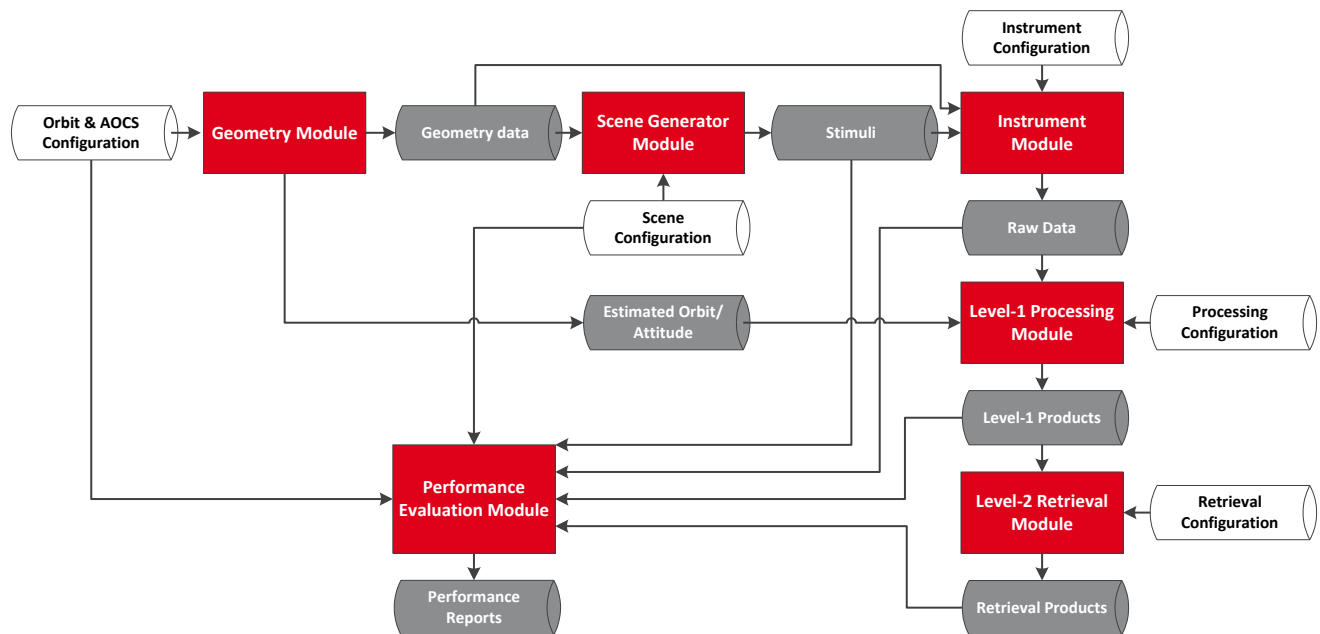

Fig. 1. Generic data flow at the highest level of the Reference Architecture

The high-level modules are:

- **Geometry Module.** In charge of simulating the spacecraft orbit and attitude, as well as the generation of the observation geometry of each instrument.

- **Scene Generator Module.** In charge of simulating the scene to be observed (terrain, ocean or atmosphere) and all environmental effects (radiative transfer models, atmosphere simulation, illumination conditions...) to be considered for the correct generation of the stimuli to be entered to the instrument model.

- **Instrument Module.** In charge of simulating the sensor behaviour, having different outputs depending on the type of instrument.

- **Level-1 Processing Module.** In charge of the generation of level-1 products, from level-1a to level-1c.

- **Level-2 Retrieval Module.** In charge of performing the retrieval of the geophysical parameters that are the objective of the mission/instrument. Depending on the mission and on its definition of the products, this module would generate level-2 data or products at a higher level of processing.

- **Performance Evaluation Module.** In charge of performing the needed analysis of the simulator outputs to evaluate the performances of the mission. It could be run at different points of the simulation chain.

Each of these high-level modules is composed by Building Blocks (BBs). A Building Block is a unit of software that performs a certain functionality.

BUILDING BLOCKS FOR EO END-TO-END SIMULATORS

The ARCHEO-E2E activity identified over 125 Building Blocks and provided a preliminary definition for each of them. As seen below, approximately one quarter of the blocks correspond to the instrument and another quarter to the L1. The Scene Generator represents a fifth and the Geometry, while the Level-2 and PEM each is less than one eighth.
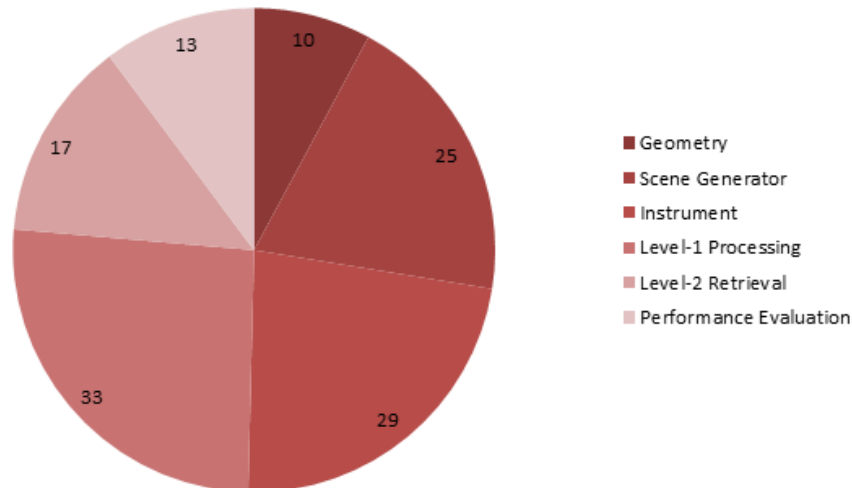

Fig. 2. Classification of Building Blocks according to Module

A thorough analysis of the outcome of ARCHEO has allowed identifying additional blocks and even splitting proposed ones into several ones depending on the configuration of the simulation.

In order to start the development of the building blocks, priority has been given to the following:

- Building a simulation chain of a generic passive optical imaging mission with the purpose of generating test data for ground processing SW validation.
- Blocks belonging go the Geometry, Scene Generator and Instrument modules.

Therefore, the Building Blocks proposed in ARCHEO have been analysed with attention to how to fit the above priorities, but also taking into account the complexity, maturity, readiness and potential for reuse. The resulting list will be implemented in the sort term and made available to the scientific community via the BIBLOS website.

BUILDING AN EARTH OBSERCVATION END-TO-END SIMULATOR (EO E2ES)

Having the Building Blocks implemented and available to the broader community is only one stage of the process for implementing an E2ES with the Reference Architecture. The main goal of the EOMODEL/BIBLOS project is to help with the construction of a new EO E2ES. There are many existing available implementations online that can be used for this purpose, but they are scattered around the web. The idea of BIBLOS is not only to give the users blocks that they can insert in their simulators, but to go one step further. The BIBLOS website will include a step-by-step guide to configure a simulator for different types of missions, different types of instruments, and different particularities. It will present in an easy and clear way how to construct an EO E2ES following a number of steps. This guide will include the following sections:

1. Workflow
2. Types of Missions
3. Generic Architecture for each Mission Type
4. Instruments, Modules and Blocks
5. Library Search

1. Workflow

The first step of the design process presents the user with the main elements of the BIBLOS design. The concept behind ARCHEO, [3], is introduced and how the user can use a common framework or their own simulation environment, to link a simulation chain with a predefined high-level reference architecture.

As shown in the figure below, the following steps shall be followed:

- The user selects the framework or environment in which the E2ES will be built. It has to be taken into account that, because of the nature of the Building Blocks and Modules, the simulation will be data-driven with the modules interfacing through the reading/writing of intermediate files. These inputs outputs are defined for each of the provided Building Blocks.

- The user selects the Reference Architecture that is more suitable to the E2ES under development (e.g. single platform and single instrument, single platform and multiple instruments sharing or not the processing, etc). This Reference Architecture will dictate the number of Modules required.

- For each Module, and depending on the type of instrument, the user refers to the internal architecture of the Module to check which Building Blocks are needed and how they should be interconected.
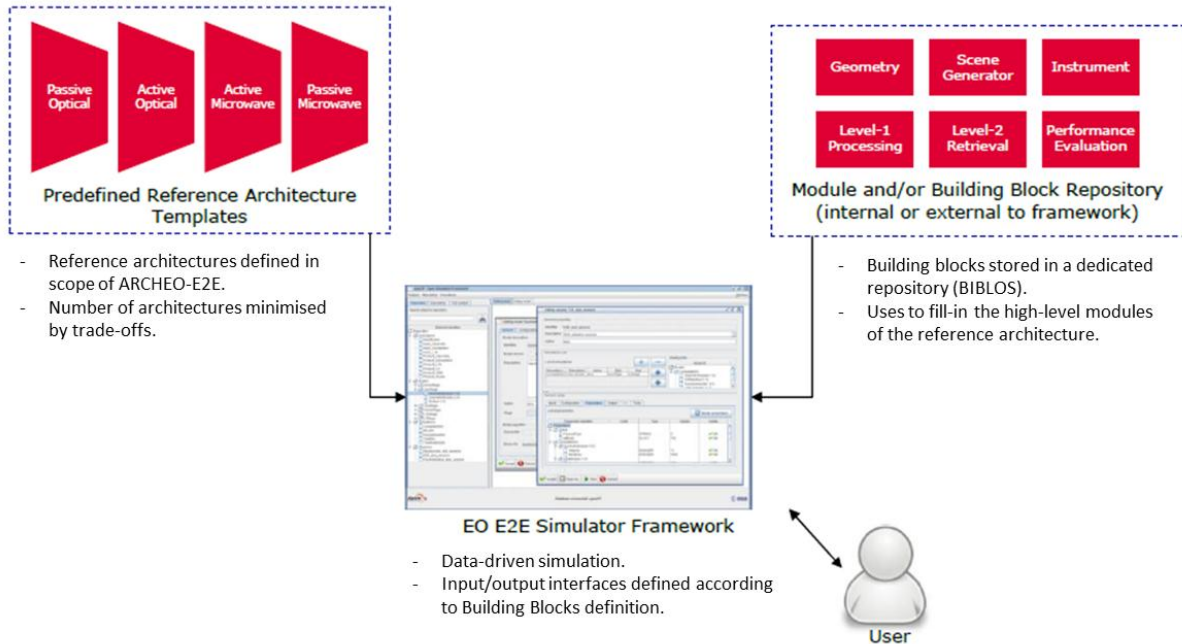

Fig. 3. Process for implementing an E2ES with the Reference Architecture and the Building Blocks

2. Types of Missions

Each mission has its own particularities. In consequence, each simulator has to be created to take into account all the mission specific elements, such as:

- If there is one or multiple instruments in one platform. And if these instruments are the same type or different.
- If there is one or multiple spacecraft. If there are multiple spacecraft, they can be flying in formation flying, loose formation flying, or no formation flying.
- In the processing (L1 and L2), some missions use a combination of products from different instruments of the same platform, or from different missions.
- The EO E2ES can use of real data from other simulations in two stages, as an input to the Scene Generation, or to generate products in L2.

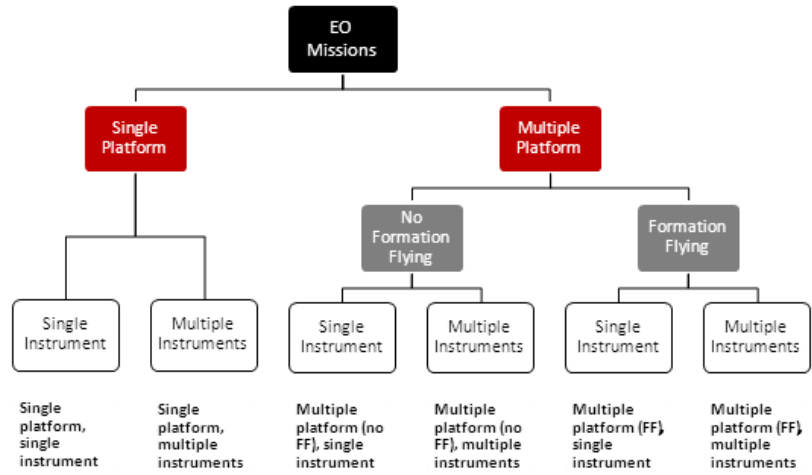Al these criteria will determine the type of mission, as shown in the following figure.

Fig. 4. Example of generic data flow at the highest level of the reference architecture (single platform / multiple instruments, sharing scene generation and retrieval)

3. Generic Architecture for each Mission Type

For each type of mission, as identified in the previous section, there is a customised architecture that combines the Modules. The Reference Architecture is the simulation chain for a single instrument in a single platform, as presented in the Introduction section. However this architecture is easily adapted to other configurations using the high-level Modules. For example, the following figure shows an alternate architecture for a mission with multiple instruments. In this case there are two instruments, and the L2 processing is done combining the L1 products of both instruments.
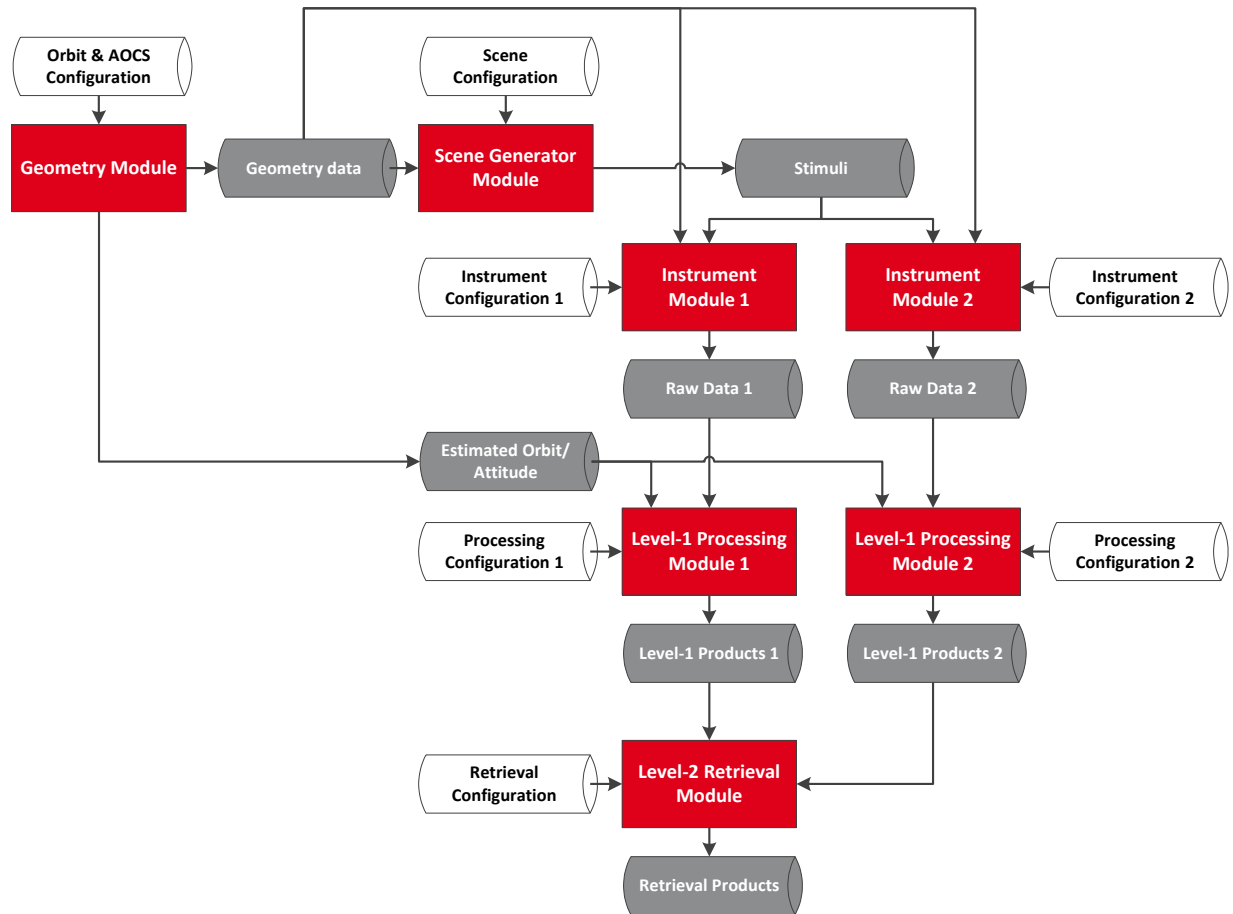
Fig. 5. Architecture for a mission with single platform / multiple instruments, sharing scene generation and retrieval

4. Instruments, Modules and Blocks

As explained in the Introduction section, there are four main instrument types for EO missions: Passive Opticals, Active Microwaves, Passive Microwaves and Active Opticals, [2]. The user shall determine the instrument(s) to be simulated, The simulation chain of any EO E2ES can be divided into 6 basic sections, called "Modules": Geometry, Scene Generator, Instrument, Level-1 Processing, Level-2 Retrieval and Performance Evaluation. Each Module is composed by Blocks. A Block is a unit of software that performs one functionality, for example the Orbit Block. The Blocks are the bricks of the simulator chain.

5. Library search

Once the architecture for the mission is defined, the user needs to download the blocks of the different modules. To do this, the website has the blocks organised per Module and Instrument type. The user will be able to search for the blocks needed to build the simulation chain.

FUNCTIONALITIES OF THE EOMODEL/BIBLOS WEBSITE

The website of the EOMODEL/BIBLOS project is a key element of the project. The website is designed to guide the user through the process of creating an EO E2ES. The features of the website are described in the following sections.

User Management

The website consists of public areas with unrestricted access, and private areas with restricted access. The Private Area allows the management and configuration of the structure, contents and organization of the EO models library, while

the Public Area provides access to the information and models library published. Anyone can see and list the content of the blocks, however to download the model data, the users must sign up in the system and be approved by the Administrator.

User Interface

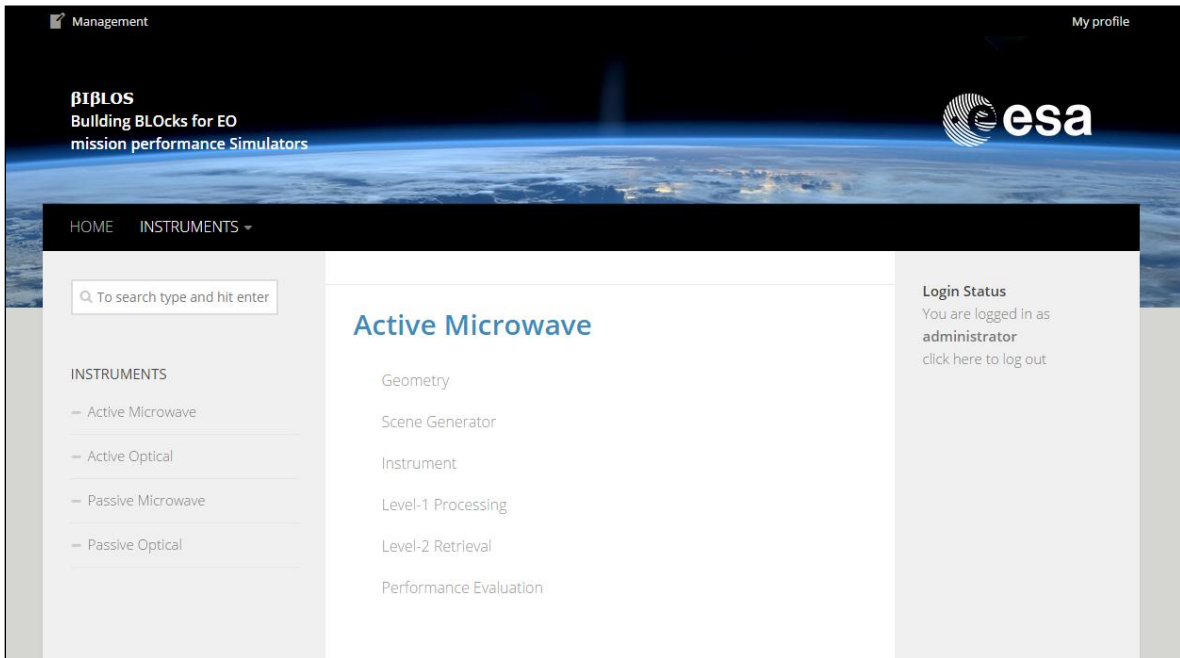The user interface of the website is shown in the figure below.

Fig. 6. Screenshot from the preliminary BIBLOS website

The site is divided into the following sections:

- Header. Web title and ESA logo.
- Menu. Two sections can be accessed from this menu:
  - Home. Homepage.
  - Instruments. There are four instruments. One of the following instruments can be selected: Active Microwave, Active Optical, Passive Microwave or passive Optical.
- Left-hand menu. Two main section are shown here:
  - Search. A widget for entering the terms user for performing the documents search.
  - Instruments. Links to the same instruments shown in the top menu described in the previous paragraph.
- Right-hand menu.
  - Login. This widget allows entering user credentials, or register as a new user.
- Main container. Project information is shown in the main container located in the middle of the web page.

Content Organisation

The content is organised in the following hierarchy: Instrument > Module > Block. As explained in the previous sections, there are 4 types of instruments (Active Microwave, Active Optical, Passive Microwave and Passive Optical). The users will first select the type of instrument and then, they will view the high-level modules (Geometry, Scene Generator, Instrument, Level-1 Processing, Level-2 Retrieval and Performance Evaluation).

Then, when a user selects the module, they will view all the blocks of that category, including the block title, and a brief description. If user clicks on "More Info" they view additional details of the block. The user will view all the information and they can download the file after login.

LIBRARY ROADMAP

The EOMODEL/BIBLOS library will be populated with blocks that will be added in a progressive way. For the first batch, blocks that form part of the satellite image chain for Passive Opticals are being selected, as explained in the "Building blocks for EO end-to-end simulators" section above. The goal is defined in [5]. These blocks include generic blocks used by all types of missions, such as the orbit and attitude blocks. Additionally, there are other blocks selected for implementation like the Line-of-Sight generation, projection on the Digital Elevation Model block, the Class Map block, the Forward Model block, one or more Radiative Transfer Models, and the spatial and radiometric blocks in the instrument modelisation. Blocks to complete the Passive Opticals and from different instruments and will be added as the BIBLOS project grows.

CONCLUSIONS AND NEXT STEPS

The EOMODEL/BIBLOS project is a unique guide for users who want to develop an Earth Observation performance simulator. Through its website, the users will be able to find an easy step-by-step guide, the reference architecture applicable to their model, and a list of Blocks to build it. This list of blocks will grow with time, offering the space community more benefits, and saving re-engineering costs.

REFERENCES

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