FEATURE

A MODEL FOR THE SCIENTIFIC EXPLOITATION OF EARTH OBSERVATION MISSIONS: THE ESA RESEARCH AND SERVICE SUPPORT

P.G. Marchetti[1], G. Rivolta[2], S. D'Elia[1], J. Farres[1], N. Gobron[3], G. Mason[1]

[1]European Space Agency – ESRIN Via Galileo Galilei I-00044 Frascati, Italy

[2]Logica D GmbH, Rheinstrasse 95 – D-64295 Darmstadt, Germany

[3]Joint Research Centre Via E. Fermi 1 I-21020 Ispra, Italy

1. Overview

The European Space Agency (ESA) is developing five new missions called Sentinels specifically for the operational needs of the joint European Commission-ESA Global Monitoring for Environment and Security (GMES) programme [1]. In the coming Sentinel era, Earth Observation community will be challenged by the significant increase of storage and processing capacity needs. Whilst the yearly growth rate of the data archives of ESA's largest Earth Observation mission, ENVISAT, has been in the range of some hundreds of terabytes, the growth rate for the Sentinel missions' data will be one order of magnitude higher.

The Sentinel missions' measurements have a scientific potential which goes well beyond the products offered by operational services. In order to foster the realization of such scientific potential, straight access to data and adequate processing resources shall be made available to the Earth Observation community. In this paper we propose the "ESA Research and Service Support" model, successfully experimented in the Envisat era, as foundation for supporting the Earth Observation research in the Sentinel data exploitation era. Starting from the theoretical basis of the Research and Service Support model, the paper provides some concrete examples of support to science, introduces tools and services that can support EO scientists in developing applications on the basis of identified science product requirements, and the integration of information from the Sentinel type missions with existing and planned science missions.

The idea behind the proposed model is that the realization of the scientific potential of future EO operational missions can be nurtured by selectively extending approach, technical environments and tools that cover different aspects of the science data exploitation, given that the generation of scientific value-added products requires several pre-conditions and follows a number of steps which are not necessarily sequential. Being this paper an introduction to the proposed "Research and Service Support" model it focuses on two high level scientific needs: the capability to generate and test algorithms; and the capability to perform near real time processing of multi-source Earth Observation mission data.

2. Motivation

Generating and testing algorithms relying on a cooperative environment where scientists can share and benefit from each other's work, find already published algorithms, combine, modify and exploit them, whilst maintaining full control and intellectual property rights of their work, would ease the productivity of any scientific community.

In particular, for the Earth Observation (EO) community, the requirement to perform near real-time processing of multi-source EO mission data entails the capability to access resources able to run the processing of large amounts of Earth Observation data.

The availability of a service providing support tools and environments enabling the possibility to generate scientific products designed around specific requirements is an important element for successful exploitation of the scientific potential of Sentinel missions.

The ESA Research and Service Support (RSS) service introduced in this paper, has been designed to the aim of providing on one hand the resources said above, and on the other hand ensuring that the research process is effectively and efficiently followed.

In order to clarify the scope of RSS, it is worth to compare it with the one of another significant service aimed at supporting the EO scientific process: the NASA's Giovanni (see http://disc.sci.gsfc.nasa.gov/giovanni). Giovanni is a web based application oriented to data visualization and statistical analysis over a number of large Earth Observation datasets; hence aiming at an end-to-end tool for supporting scientific work.

RSS has a different ambition, offering a front-end for data access and processing, relying on software tools made available by ESA for local data analysis at the user desk. ESA provided EO software toolboxes are available at http://earth.

esa.int/resources/softwaretools/. This approach is particularly adequate for those users who have started their work locally on their workstations with some data samples and want to "scale up" to massive data processing or wide service exposure. Also, many users rely on the RSS for the pre-processing of large data amounts, leaving their experimental tasks to run locally at their own labs.

3. Challenges and Support Models

After the launch of the European Remote Sensing satellites ERS-1 and ERS-2 in the nineties, the large growth of Earth Observation data availability, started less than a decade ago with the launch of the Environmental Satellite—ENVISAT and more recently with the Earth Explorer science and research missions [2], has opened new great opportunities for performing Earth Observation science. The plans of new ESA missions indicate 5-10 times more data to be acquired and archived in next 10-15 years. On the other side since 2004 the total number of ESA approved EO research projects, has been strongly growing. Such trends suggest that EO researchers' capability might be challenged by the possible limitation of infrastructural resources available within their research centres. The demand on research centres to follow the growth in storage and processing capacity might represent one of the major barriers for EO scientists to perform high quality research with the large amounts of data which the new missions will make available in the coming years. The Sentinel missions planned within the European global monitoring for environment and security programme—GMES, will be operational from 2013 onwards [1], [3]. The exploitation of the scientific potential of these new types of missions would imply significant investments on research infrastructures, which may be a huge challenge for performing EO research.

Identifying challenges and removing barriers have already been demonstrated to be effective ways to make easier EO research. In the last few years, indeed, EO data online availability and simplified EO data user registration have undoubtedly sustained the growth in the number of EO research projects performed on ESA missions. Such results suggest that removing the challenge of a fast growing storage and processing capability from the scientists' owned research infrastructure might enable a growing number of EO research projects and an enhanced capability to perform science over a large scale of geospatial and Earth Observation data and global phenomena.

In addition it is recognised that holding regular EO workshops and symposia not only stimulates the networking and exchange of ideas, but is a key driver for stimulating research. Such activities on one hand enable scientists to access relevant information and resources, and on the other hand reinforce the sense of EO research community, consequently activating new research initiatives and the exploration of possible cooperation and other synergies.

Therefore, it can be said that an effective and efficient service of support to EO researchers should provide them with adequate processing capability and allow users to be part of a community with access to information and resources.

We have designed the Research and Service Support (RSS) service architecture to empower scientists with solutions to the two challenges above identified. As part of ESA's Earth Observation Ground Segment Department, the RSS service has the mission to provide tools and services that support the EO community in exploiting EO data, the researchers in developing applications and the service providers in generating value-added information.

The service makes available to EO researchers (from research centres, universities, or even industry) resources for their EO research. "Resources" means processing capacity, such as a Grid environment (with online access to EO data from ESA and non-ESA missions) [4] where RSS users can test a new algorithm on large datasets, improve and validate it, re-iterating this process until the scientific goal is achieved. RSS processing environment and other RSS resources available for supporting EO researchers is described in the following sections.

The approach used to tailor the RSS service is to follow the scientist's viewpoint within a generic scientific research process and to provide support where data access, storage and processing may hinder the scientific research process. For the purpose of describing the RSS service, the scientific research process can be conveniently separated in different sub-processes or steps. The effort related to some of such steps can be drawn from other sources, when available.

We base our model for the generic scientific research process on the high level requirement that science needs to grow and progress. For that purposes theories need to be tested - as indicated in the classical work of Popper about the growth of scientific knowledge [5]. Popper makes reference to the method of learning by trial and error. He places it in the context of the progress of science, seen as the possibility to test a theory, to refute it, and even to know before a theory has ever undergone an empirical test, to say whether, provided it passes certain specified tests, it would be an improvement on other theories.

What is important to remark here is that for a theory the criterion of potential satisfactoriness is the *testability of the theory*. This means that is possible in general to compare the severity of the tests and even to define a measure of the severity of the tests.

As a matter of fact in our work we address only one of the "three requirements for the growth of knowledge" [5], pp.326. We disregard here the aspect of theory unification (e.g. Newton's theory superseding and unifying Kepler's and Galileo's theories) as we support the development of theories within the EO domain. For the sake of completeness we must say that we therefore disregard here Popper's formalisation of the link

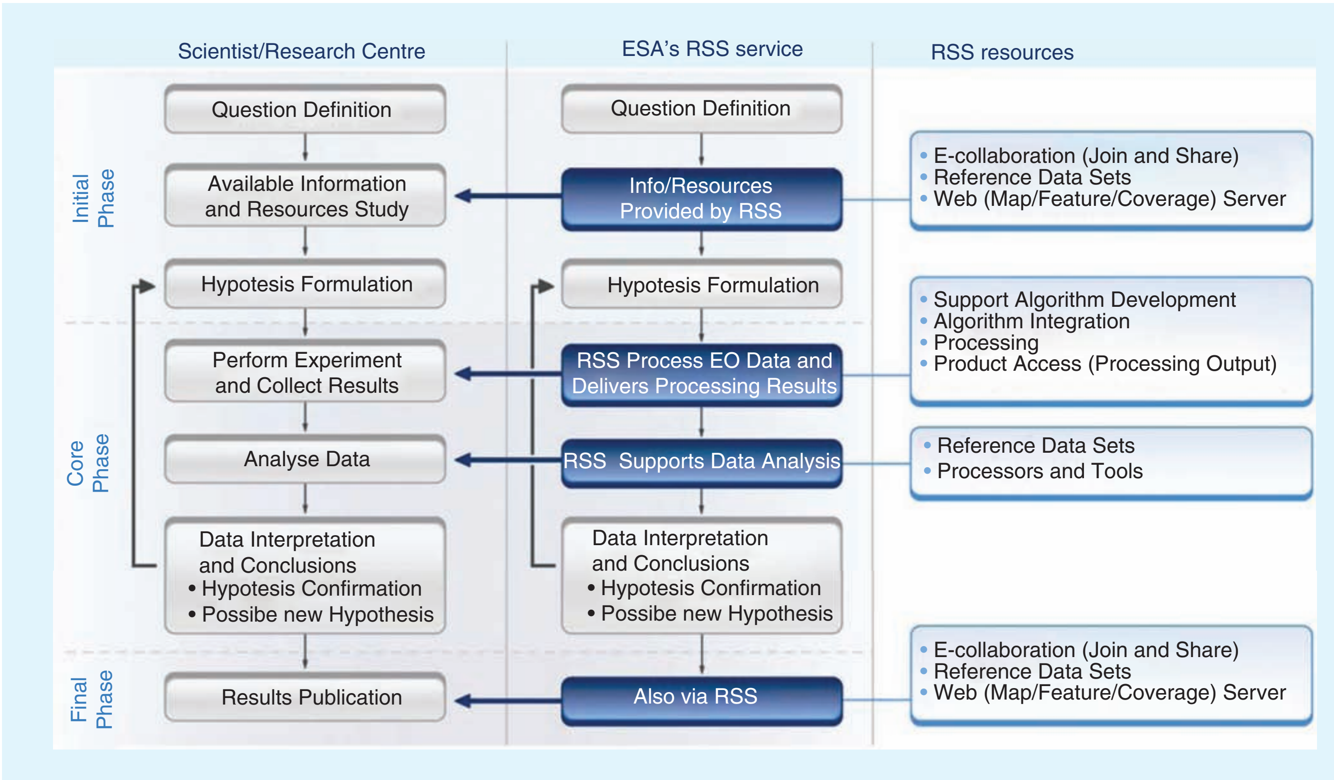

Figure 1. Research Process and RSS service.

between probability and content of a theory, which is useful in particular to address the theory unification, as well as to describe the probability of a theory being corroborated on the base of previous knowledge. We are in fact interested in the day to day work of scientists in the EO domain where small improvements to existing theories are as well important.

Popper defines (ibid. page 548) a high level process for the evolution of the theories:

$$P_1 \rightarrow TT \rightarrow EE \rightarrow P_2 \qquad (1)$$

on which we base our EO research support model visualised in figure 1 above.

In the above process (1): P_1 is the problem from which we start, TT are the tentative theories by which we try to solve the problem, EE is the process (critical analysis, experiment or test) which we use to verify the theories, and P_2 is the new problem which emerges as consequence of the knowledge growth sustained by the process of scientific discovery. Our research support model—described below—supports another important requirement from Popper's work that is that new theories should be *independently testable*.

So expanding from the high level process (1) described above, a generic research process could be schematized as in the left panel of Figure 1.

In the central panel we highlight the sub-processes where RSS can have a support role by providing resources to EO scientists. Three phases can be distinguished.

The first phase of the research process is composed of three steps going from open questions to hypothesis formulation. The first step, addressing the selection and definition of the scientific question to deal with, initiates the process. The second step represents the sub-process aiming at gathering, organizing and evaluating available information, in order for the scientist to formulate the hypothesis in the successive third step. In this phase, RSS can contribute playing the role of information/resources provider.

The core phase is composed by steps four to six. In the fourth and fifth sub-processes, experiment and data analysis, respectively, RSS can provide a very significant support. The experiment, that in the case of EO research means data processing, can be supported by RSS not only by means of the mentioned Grid processing environment, but also, above all, by making available resources and services such as support to algorithm development, algorithm integration, product access and delivery. The data analysis step can be also supported by RSS by providing specific reference data sets, processors and tools, in order for the researcher to confirm or re-formulate the hypothesis in the successive sixth step.

Finally, the third phase regards the results publication. The concept of publication of results may go well beyond the publishing of scientific paper. It is linked to the networking need identified above. This sub-process can also benefit from RSS resources such as the Join&Share environment for e-collaboration, the Reference Data Sets (RDS) and the map and raster data publishing environments.

Such environments allow the scientist to network, communicate and publish the results, in addition to the usual channels, sharing knowledge, information and data within the EO community.

Considering the near future EO research scenario, it can be said that the process of furthering science will more and more require access to terabytes of data that will be produced daily by the Sentinel type missions and to petabytes of data accumulated in the long run. The issue of moving around terabytes or petabytes of data, has been the subject of a wide effort in information technology leading to developments in Grid and cloud computing. The basis for such approaches is the goal of exploiting computing resources such that the processing capability of each computing node is always utilized and computing resources are optimised. Making science in the Earth Observation domain in the Sentinel era will require moving and storing terabytes or petabytes of data that will imply significant cost, often unaffordable for small research centres. This is the reason why models of data processing which minimise the data access issue have shown to be successful.

4. The Current Research and Service Support

The recent history of the RSS service support via the Grid Processing On Demand (G-POD) [6], lists a lot of examples of algorithms developed by principal investigators for their science purposes, which have reached a much wider use beyond the initial community and use case. Examples based on MERIS products from the medium-spectral resolution, imaging spectrometer on board of the ENVISAT Satellite are:

- The MERIS Global Vegetation Index (MGVI), on demand, i.e. the Photosynthetically Active Radiation algorithm over a user-defined aggregation period of time and with 1 km resolution area of interest [7];
- The AeroMeris product, designed to extract all the information provided by MERIS Level 2 for a small area in an easily accessible format. To this end the user can specify area and time of interest, and obtain several files with all the information available in the Level 2 MERIS product;
  - MERIS Level 3 water, land and atmosphere products like e.g.
  - Chlorophyll Concentration for the open ocean [8];
  - The aerosol optical thickness at 443 nm and the angstrom coefficient;
  - Albedo16-days averaged maps of spectral and broadband albedos at a spatial resolution of $0.05° \times 0.05°$;
  - Water vapour over clear sky.

As an example of the general process of algorithm development, test and deployment over processing on demand environment, the MGVI case is reported in the following section.

4.1 MERIS Global Vegetation Index: A Success Story

The contribution of the Research and Service Support to the exploitation of EO missions' scientific potential is demonstrated via the success story of the development of MERIS derived products based on the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) algorithm, developed and owned by the Joint Research Centre, which expresses the fraction of incoming solar radiation useful for photosynthesis that is actually absorbed by vegetation. RSS supported the process of algorithm development, test and deployment over a general purpose processing on demand environment dedicated to the scientific exploitation of EO data generated by ESA missions, as well as the provision of tools and environments in support to that process.

The FAPAR value is estimated from daily MERIS spectral measurements in the blue, red and near-infrared bands acquired at the top of the atmosphere using a physically based approach [7] and [9].

The MERIS land Level 2 product is operationally provided in the Space Oblique Mercator (SOM) projection at the reduced resolution, i.e. at 1.2 km spatial resolution. Establishing long term time series of remote sensing geophysical products, that are relevant for environmental applications at regional or global scale, allows the production of Level 3 products. These latter correspond to lower temporal composite, e.g. 10-day or monthly period, and/or at a lower spatial resolution relevant for carbon or climate modelling communities. The spatially aggregated land products are therefore produced to be directly used for regional or global scale land analysis.

The time composite algorithm is based on the selection of the day over the time compositing period (10 consecutive days or 1 month) that corresponds to the most representative value of FAPAR, [10]. In order to make such temporal composite, a code has been developed and its executable implemented in the G-POD facility to produce daily products in a rectangular grid which are then used to make either 10-day or monthly products. Figure 2 shows an example of results over Europe from daily to 10-day products. The products are systematically produced and delivered via FTP at the Service Support Environment portal (http://services.eoportal.org/) on near real time.

The lower resolution products like the global ones at 0.5×0.5 degrees are produced by spatially aggregating 1.2 km products over a low spatial resolution window (the same or a different geographical window). The code searches for all pixels (e.g. the input pixels at 1.2 km) that are located in each grid cell of the new geographical region (output window). These pixels are then combined together by applying an operator to their values.

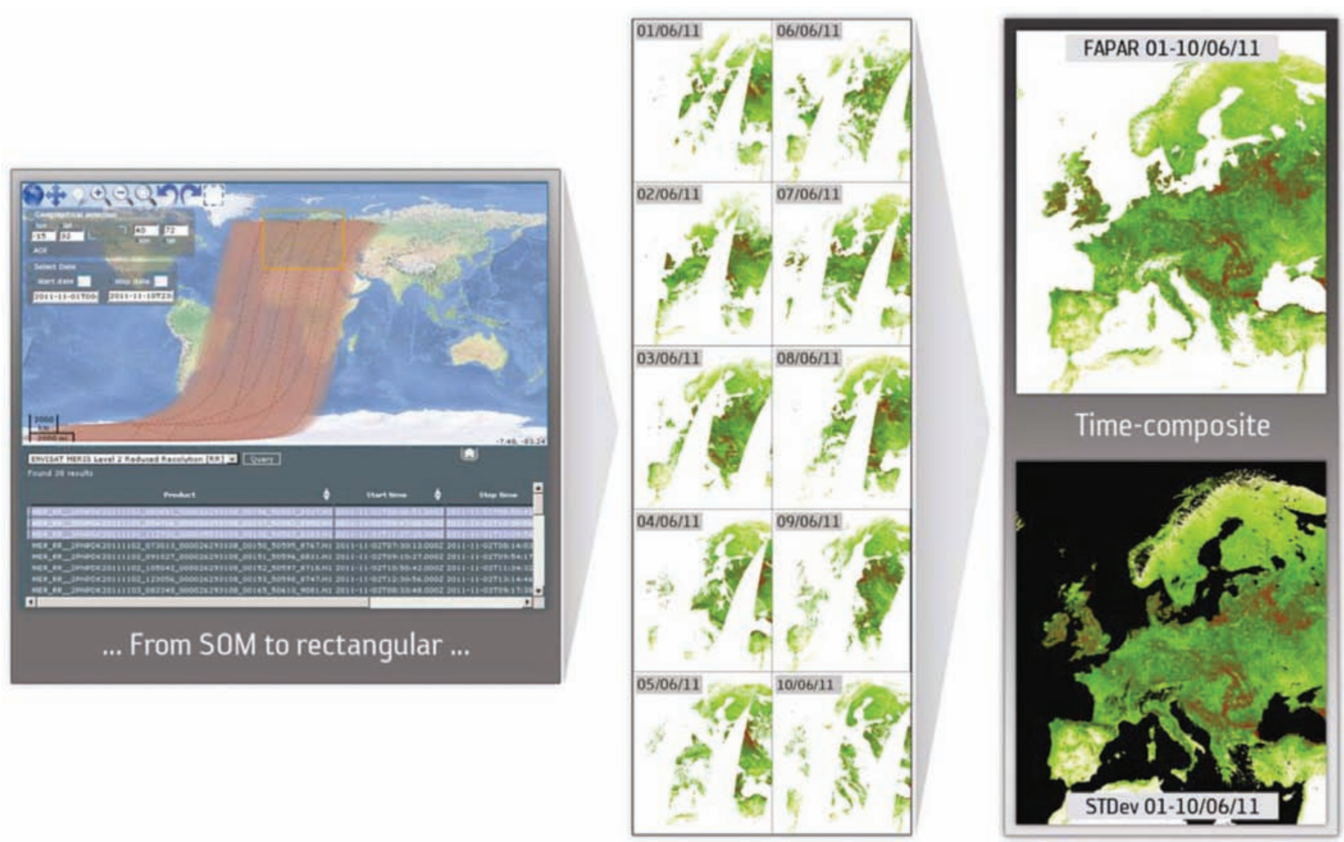

Figure 2. Example of production of 10-day FAPAR using G-POD environment.

The algorithm of aggregation implements two operators:

- computation of the mean, standard deviation, number of samples and
- computation of the median;

The averaged values refer mostly to the geophysical measurements, like the FAPAR and associated values and the median values are used when the geometry of measurements (such as the sun and observation zenith and azimuth angles) are reported. These global products correspond to the demo level 3 products that are automatically published at http://earth.eo.esa.int/level3/meris-level3/ and have been used in the scientific community for monitoring the state of land surfaces, see [11] and [12].

Similarly to the MGVI, other projects which have been supported and hosted by G-POD are: Flood Monitoring [13]; Aerosol Properties [14]; Volcano Monitoring [15]; Fire detection [16] and many other fields like Land Surface Temperature, Aerosol Optical Depth, Land cover classification and Alga Monitoring.

5. Use Cases

5.1 Research and Science Use Case

Within this use case a scientist principal investigator has the objective of performing scientific activity along the lines of the process modelled by Figure 1. We will concentrate here on a subset of high level requirements where RSS support can help to maximise the results, reducing the effort at the researcher side. They can be summarised in following needs:

- to be able to concentrate on algorithm development;
- to access (or easily create) a validation data set (possibly with heterogeneous data, as well as with many and very diverse data takes);
- to perform several processing runs against the validation data set in order to tune and validate the algorithm;
- to get continuous feedback on the ongoing work and issues encountered by the community of peers.

Once these steps are completed and the algorithm validated, the scientist would like to see the result of the work systematically applied on past data (bulk data access) and / or fresh data.

In support to the above mentioned scientific needs a 5-level service model has been defined, ranging from Basic Science Support Services up to support to Product Validation, and further to Production and Service Support. A detailed description of the proposed support is provided in section 7. Such model is implemented via the Research and Service Support service introduced in section 4.

5.2 New Scientific and Collaborative Product Development and Validation Use Case

The GMES Space Component [3] addresses the Sentinel data exploitation within a GMES Contributing Mission ground segment consisting of two elements:

- the Core Ground Segment providing Sentinel missions products generally up to Level 1B or 1C, data products from the Contributing Missions, coverages or 'time series' composed of products from multiple satellites and
- the Collaborative Ground Segment, providing supplementary functions to Sentinel Missions data, e.g. either through specific data acquisition, processing, dissemination, or specific data products (the access to GMES Contributing Missions is supported within the GMES Space Component).

The Core and Collaborative Ground Segment concept is illustrated in Figure 3.

The process of developing new scientific and/or collaborative products may need adaptations and validation which may entail additional processing steps to be performed within the same environments supporting the science use case.

The RSS service in support to scientists offers a model on how to complement the payload data ground segment scenario, which foresees a dedicated service to data users, enabling their data processors to run in the ground segment processing environment. The RSS model allows the development of additional (scientific) products to complement the base product list provided through the core ground segment services.

The goal of the proposed RSS service model is to foster the scientific use of EO operational missions data and the development of new derived products, by enabling remote access to and processing of ground segment core products according to user-provided algorithm implementations. Through collaborations with scientific research the service providers will be able to define and develop new and complementary value-added products (e.g. Level-2, 3), validate them on large datasets, and finally swiftly transfer the products to sustainable operations for global usage.

6. The Research and Service Support Architecture and Environments

Research and Service Support has developed environments targeting different steps in the research process and defined a support model [17]. Besides making available specialised data, e-collaboration environments and related expertise for application development, as well as bulk data access and processing for higher level products' generation and provision, RSS has also the framework for the development of advanced technology and tools in various ground segment areas like resource identification and access, chaining of processors and services, information/feature extraction, interactive data analysis. Further information can be found at http://rssportal.esa.int

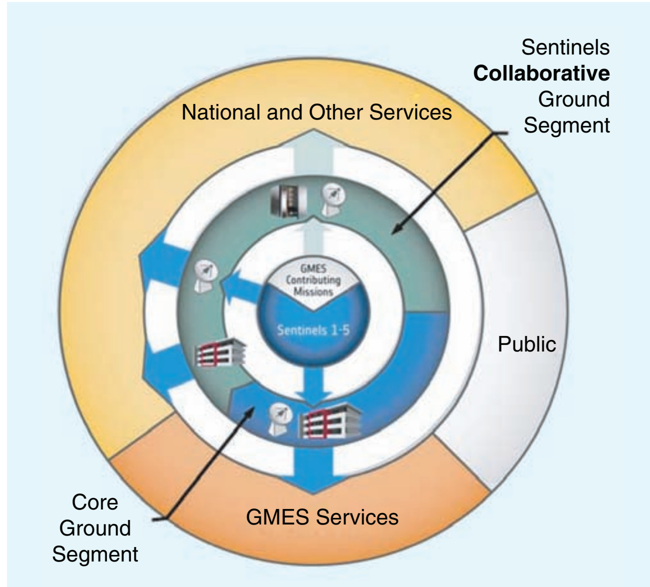

Figure 3. Core and collaborative ground segment concept.

The increase in EO data use within more and more applications is making available also other resources useful for feature/information extraction, such as chainable services and processing components. Therefore the key resources are now data (products archived in repositories and described through catalogues' metadata), processors and services. Because of their proliferation, methods for their easy and semantic (in application terms) identification are necessary.

RSS is working through technology projects on new methodologies, based on ontology/semantics, for the identification and use/activation of resources. Examples of these activities are:

- harmonised enhancement of catalogue metadata standards for the inclusion of semantic search terms (describing the features/information contained in a product);
- semantic product search (identification of products with a specific content);
- resources' registry and discovery;
- automated chaining of resources.

Our model of scientific research described in section 3 concentrated in an objective or logical view of the scientific knowledge and of the research process having as reference the work of Popper [5]. We have to note that in order to take into account the actual direct exploitation of EO data in particular in image analysis and image information mining a subjective or psychological view based on user's conjecture is needed as outlined in [18]. Additional work is still needed to cover the link between user conjectures, perception and semiotics, see [19] (note this reference does not cover the EO domain). In particular when analysing an EO product the user is expressing the conjecture that a feature relates to a particular object (e.g. this feature denotes an urban settlement) both

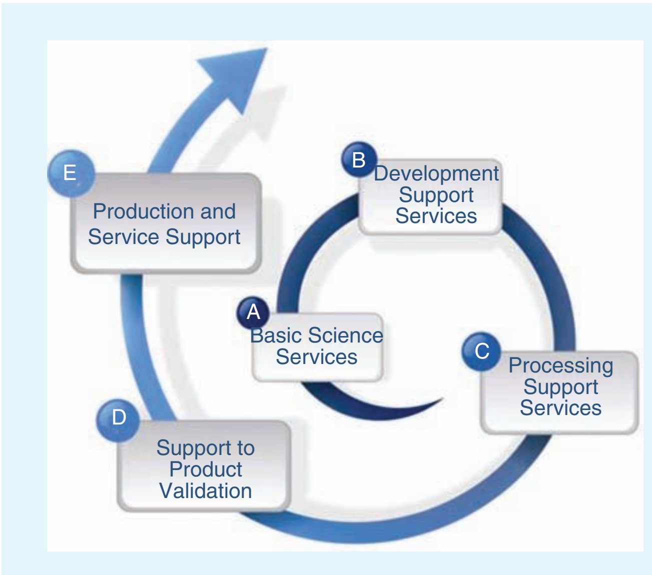

Figure 4. The 5-level RSS research process support model.

the subjective perception and classification aspects play a role. Such approach falls within the scope of knowledge-based information mining.

The possibility to interactively analyse entire image collections for searching features to be defined by the user interactively, is relevant from an application point of view and scientifically very attractive. Research has been performed and prototypes developed aimed at permitting to interactively search and tag (label) large or well characterised areas (features) within an entire collection of images.

A knowledge-based information mining approach is therefore substantially different from the model we propose in section 3, as it includes an ingestion phase (unsupervised), during which all the images of the collections are processed to automatically extract Primitive Features (like spectral, texture or geometric information) [18], and an interactive phase (supervised), where the user can train the system through positive or negative feedbacks on sample images, apply the trained "feature label" to the entire collection. The user can as well define (label) the semantic image content which is linked (e.g. by Bayesian networks [20]) to a completely unsupervised content-index. Based on this stochastic link, the user can query the archive for relevant images and obtain a probabilistic classification of the entire image archive as an intuitive information representation.

7. Support Model for the Defined Use-Cases

From our point of view, in order to support the two use cases described in sections 5.1 and 5.2, we have as well to take into account the need to ensure that:

- the routine production of EO products for operational services is not affected by research and science activities, nor by the development of new or higher level products;
- the objectives long term archiving and data preservation of EO data are fulfilled within the context of a cost effective architecture, and in particular that the data access and processing for scientific purposes is efficient.

The consequences of the above high level requirements and objectives are that:

- algorithm development is made easy and validation is supported;
- reference datasets are available to the communities;
- a dedicated processing and re-processing environment shall be available to the science users and the service developers.

In order to implement these statements RSS has developed a specific service model. Such model, intended for supporting the research process described in Figure 1 in its different steps and phases, is schematized in the following Figure 4.

The model is organized in 5 levels, from A to E: Basic Science Services, Development Support Services, and Processing Support Services, Support to Product Validation, and Production and Service Support.

The first level, or A, Production and Service Support, encompasses the access to EO Data through standard Query-Order services and to free Toolboxes for EO Data Processing. These services are used over the full research process from the first step Available Information Study (see Figure 1).

The second level, Development Support Services, covers the access to EO resources and toolboxes/processing components for algorithm development and test. These services are employed during the Hypotheses Formulation step for the preparatory work leading to the Perform Experiment and Collect Data step. This type of service is provided through specialized facilities and applications supporting software development and re-use, data management, processor testing.

The third level, Processing Support Services, includes the access to Grid and/or Cloud Computing resources [21], enabling mass data processing and collection of results. These services are required during the Perform Experiment and Collect Data step. Processing and data handling needs are typically very high and concentrated in time; hence the service model foresees the use of a shared (and scalable) facility.

Level D, Support to Product Validation, foresees the provision of reference data like ground truth or independently produced products and related processing resources required to conduct the validation. These services are essential to establish the quality of the processing and a pre-requisite for any collaborative product.

The last level, or level E, Production and Service Support, covers the configuration of new services allowing the systematic data processing in near real time and/or on long time series. Also covers the management of user access to the new services and the possibility of service orchestration. These services are linked to the Publish Results activity, when the research has been concluded and the results are made available to the community.

Although ESA already provides Research and Service Support for most of the activities/levels described above, these services will need to evolve in line with the future needs. In particular, the following challenges should be addressed:

- Enhance Data Management and Processing capabilities by one order of magnitude in line with Sentinel data volumes;
- Cover activities of the research process which are little supported like the product validation;
- Support innovative technologies such as efficient data base technology for product time series, very large parallel computing devices, etc.

8. Research and Service Support: Future Evolution

The RSS model described above has been successfully experimented in the ENVISAT era. A fundamental question to answer is: how shall RSS evolve to confirm and if possible increase its value for science in the Sentinel era? To answer this question it needs to be considered that Sentinel type missions pose three important challenges to RSS service:

i. Large Data Volumes in the Order of 2TeraBytes a Day

Data Management at RSS is critical to a good service and requires fast access to (almost) all the data products generated. This is currently achieved by three sourcing modalities: copying rolling archives, caching data from on-line archives and moving off-line data on-line. Nowadays, the proportion is roughly 70-10-20 for the three modalities. Considering the data volumes from future EO operational missions, the proportion is expected to evolve towards a 20-70-10. That is, off-line archives will tend to be replaced by on-line archives and, due to the data volumes involved, copy from other archives will not be affordable. Instead, intelligent caching over large on-line archives is to be foreseen. Therefore topics currently under research and development are:

- Optimization of data circulation for caching purposes: data granularity, network configuration, seeding strategy;
- Caching strategies based on use-patterns, trying to “guess” which data will be requested next.

Simple precursors have been developed to bridge the ESA Grid Processing On-Demand (G-POD) environment with MERIS Catalogue and Inventory data source and various FTP repositories at ESA facilities.

ii. Growing Importance of Multi-Temporal Analysis

As a result of the systematic data acquisitions over long time periods (>20 years) and with high revisiting rates (<5 days), demands on time-series analysis will grow.

Optimizing data organization and retrieval/access to EO archive for such usage will be a challenge. Database techniques associated with Services for publishing raster data are being introduced in RSS for this purpose.

iii. Very Large Processing Requirements

Current processing architecture is based on a private Grid-processing paradigm.

This architecture has provided sufficient processing power over many years with very significant scalability and versatility. However, compelled by the very large processing requirements and, at the same time, by the advent of large cloud computing facilities, the architecture has recently evolved in the following direction:

- Virtualization of all local hosting infrastructures, in particular Grid working nodes;
- Deployment of cloud computing resources on the Grid;
- Location of large storing services for dissemination purposes.

This trend will lead in the coming years to the hosting of RSS environments over cloud computing facilities which will provide global scalability potential.

9. Conclusions

The ESA RSS service presented in this paper has successfully supported EO research and applications development during the last years, by making available processing capacity on online data and ensuring that the research process is effectively and efficiently followed.

As a matter of fact, RSS has over time acquired the expertise required to develop advanced environments in support to science and research - also included e-collaboration - in the development of applications, using not only EO products. These operational environments permit cost and time reduction for the design and implementation of new algorithmic solutions. Moreover, algorithms can also be run noticeably faster than at the researcher site (e.g. hours versus days) using huge data sets available online.

RSS environments permit to support the key phases in the research process also through the competence of the operational team, with scientific background and large experience both in the infrastructure and in the interaction with researchers.

Passing from the Envisat era to the Sentinel era will pose three main challenges to RSS: increased data volumes, growing importance of multi-temporal analysis and increased processing requirements. In response to each of these challenges RSS is defining adequate solutions, such as new storage strategy, new environments covering emerging needs and new processing strategy (e.g. based on virtualization, cloud computing).

ESA is willing to continue, and expand this support also to the Sentinel era, where scientific and collaborative products are a challenge and at the same time an opportunity for a more complete utilisation of the huge amount of data becoming available.

References

[1] J. Aschbacher, T. Beer, A. Ciccolella, M. P. Milagro & E. Paliouras, GMES Space Component: status and challenges, ESA Bulletin no. 142, May 2010

[2] G., Megie, C.J. Readings, The Earth Explorer Missions—Current Status (2000) *Earth Observation Quarterly*, July 2000.

[3] Liebig, V., Ashbacker, J., Kohlhammer, G., Zobl, R., (2007) GMES global monitoring for environment and security: The second European flagship in space, *ESA Bulletin*, No. 130, May 2007.

[4] I. Foster, C. Kesselman, The Grid: Blueprint for a New Computing Infrastructure *The Elsevier Series in Grid Computing*, 1998

[5] K. Popper, (1963) Conjectures and Refutations, Routledge reprinted 2010, pp. 290–338

[6] J. Farres, E. Mathot, S. Pinto, G-POD: A Collaborative Environment for Earth Observation at the European Space Agency, *Proceedings of the ESA Living Planet Symposium*, Bergen, Norway. *Special Publication SP-686 on CD-ROM, ESA Publications Division*, European Space Agency, Noordwijk, The Netherlands, 2010

[7] N. Gobron, B. Pinty, M.M. Verstraete, and Y. Govaerts, The MERIS Global Vegetation Index (MGVI): Description and Preliminary Application. *International Journal of Remote Sensing*, 20, 1917–1927, 1999

[8] J. F. R. Gower & S. A. King: Distribution of floating Sargassum in the Gulf of Mexico and the Atlantic Ocean mapped using MERIS, International Journal of Remote Sensing, 32:7, 1917–1929, 2011

[9] N. Gobron, B. Pinty, O. Aussedat, M. Taberner, O. Faber, F. Mélin, T. Lavergne, M. Robustelli, P. Snoeij, Uncertainty Estimates for the FAPAR Operational Products Derived from MERIS—Impact of Top-of-Atmosphere Radiance Uncertainties and Validation with Field Data. *Remote Sensing of Environment,* 112(4), 1871–1883. Special issue: *Remote Sensing Data Assimilation*. Edited by Loew, A, 2008

[10] O. Aussedat, N. Gobron, B. Pinty, and M. Taberner, MERIS Level 3 Land Surface Time Composite—Product File Description. *Institute for Environment and Sustainability*, EUR Report n. 22165 EN, 1–20, 2006

[11] N. Gobron, A.S. Belward, B. Pinty, W. Knorr Monitoring Biosphere Vegetation 1998-2009. *Geophysical Research Letters*, 37, L15402. DOI: 10.1029/2010GL043870, 2010

[12] M. Jung, M. Reichstein, P. Ciais, S. I. Seneviratne, J. Sheffield, G. Bonan, A. Cescatti, J. Chen, R.A.M. de Jeu, A. J. Dolman, (Han), W. Eugster, D. Gerten, D. Gianelle, N. Gobron, N., & al. Recent Decline in the Global Land Evapotranspiration Trend Due to Limited Moisture Supply. *Nature*, 467(7318), 951–954, 2010

[13] R. Cossu, E. Schoepfer, P. Bally, L. Fusco, Near real-time SAR-based processing to support flood monitoring. *Journal of Real-Time Image Processing*, 4(3), 205–218, 2009

[14] A. Kokhanovsky, G. de Leeuw, Determination of Atmospheric Aerosol Properties over Land using Satellite Measurements. *American Meteorological Society*, 235. DOI:10.1175/2008BAMS2669.1, 2009

[15] M. Manunta, F. Casu, R. Cossu, L. Fusco, S. Guarino, R. Lanari, G. Mazzarella, and E. Sansosti, E. Volcano deformation analysis based an on-demand DInSAR-GRID system: the SBAS-GPOD solution, *Geophysical Research Abstracts,* Vol. 11, EGU2009-9766, 2009

[16] M. Diagne, Drame C. Ferrao P.G. Marchetti, S. Pinto, G. Rivolta, Multisource Data Integration for Fire Risk Management: The Local Test of a Global Approach, *IEEE Geoscience and Remote Sensing Letters*, Vol 7. No.1, January 2010, 93–97, 2010

[17] S. D'Elia, P.G. Marchetti, Y. Coene, S. Smolders, A. Colapicchioni and C. Rosati, Architecture and Services for Computational Intelligence in Remote Sensing, (pp. 61–97) in *Computational Intelligence for Remote Sensing*, Grana M., Duro, R. J. (Ed.), Springer, 2008

[18] M. Datcu, H. Daschiel, A. Pelizzari, M. Quartulli, A. Galoppo, A. Colapicchioni, M. Pastori, K. Seidel, P.G. Marchetti, S. D'Elia (2003) Information Mining in Remote Sensing Image Archives—Part A: System Concepts *IEEE Transactions on Geoscience and Remote Sensing* Vol. 41, No. 12, December 2003, 2923–2935, 2003

[19] U. Eco, Kant and the Platypus, Random House, 2000

[20] M. Datcu, K. Seidel, and M. Walessa, "Spatial information retrieval from remote sensing images. Part I: Information theoretical perspective," *IEEE Trans. Geosci. Remote Sensing*, vol. 36, pp. 1431–1445, Sept. 1998.

[21] M. Ambrust, A. Fox, R. Griffith, A.D. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica, M. Zaharia, A View of Cloud Computing. *communications of the acm*, April 2010, vol. 53, no. 4