Behind the Scenes at the DLR national Satellite Data Archive, a Brief History and Outlook of Long Term Data Preservation

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ABSTRACT

The *Earth Observation Center* (EOC) at the *German Aerospace Center* (DLR) is the center of competence in Germany, providing expertise in earth observation research and development activities, as well as operational tasks for data reception, processing and archiving. We briefly present the *German Satellite Data Archive* (D-SDA) with systems and activities that make it possible to accomplish successful *Long Term Data Preservation* (LTDP) over more than 20 years with nearly exponentially growing data capacity. Tables, facts and figures exhibit the path taken at DLR to successfully establish the infrastructure for long term data preservation for Germany and Europe. Our experience is that that LTDP is manageable but requires following the evolution in technology, new usage scenarios and data policies. DLR is working on the continuous evolution of the flexible DIMS components, infrastructure and management services to serve the processing and archiving centers for the next generation earth observation satellites.

Keywords: Archiving Technology, DIMS, PDGS, Information Mining, User Services

INTRODUCTION

The *German Aerospace Center* Remote Sensing teams realized in the 1980s the need to use computational architectures instead of film material for Earth Observation data. Several mission specific ground segments where established for deep-space missions (HELIOS, GIOTTO, etc.), followed by Earth Observation missions like ERS-1. First generalization efforts in 1990 started with the user services system *ISIS*. Technological advances with the Internet and personal computers empowered DLR to make Remote Sensing data accessible to an ever growing user community.

DLR performed an analysis of the early *World Wide Web* (WWW) browser technology in 1992, finding it yet inadequate for the user services, hence the German Remote Sensing Data Centre (DFD) introduced its graphical user interface GISIS for Windows 3 PCs and UNIX users. Next task was establishing standardized protocols to access distributed Remote Sensing catalogues. In 1995 DLR contributed to the Catalogue Interoperability Protocol (CIP) teaming with the international CEOS and WGISS working groups, with the INFEO (Information system for Earth Observation) project and financing from the JRC (Joint Research Center of the European Union, located in Ispra, Italy). High quality development processes, following the ESA BSSC conventions, were introduced and followed by the projects. The web technologies were still not suitable for the desirable performance for user services (Netscape 4 and IE 3). Fomenting joint efforts in multi-mission services, DLR supported ESA in work on their Multi-mission User Interface Services (MUIS), the ESA *EOLI Web Applet* and the DLR EOWEB (Earth Observation on the Web).

The object oriented programming language Java, after initial hiccups, proved to be right choice for client and server implementations. The speed of new personal computers and huge advances in standardization, in last few years, make web browser an excellent choice for deploying and running user client interfaces.

In Figure 1 we can see how the EOWEB User Interface evolved into a modern information retrieval system which uses standardized interfaces like CIP, OpenSearch and HMA in the background. Further web-server standards like OGC WMS and WFS provide high quality background maps for new clients.

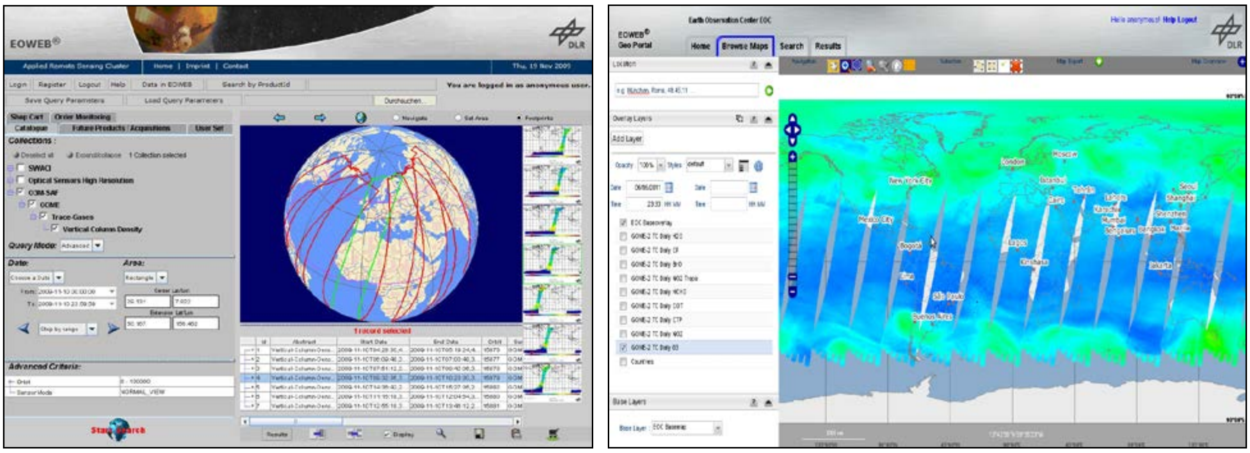

Figure 1: DLR EOWEB evolution into EGP User Interface

In parallel to the standardization efforts of the user services and access protocols, DLR established the *Data and Information Management System* (DIMS) based on a Service Oriented Architecture for a fully automated Long Term Archive (LTA) using robot, tape and *Hierarchical Storage Management* (HSM) technologies. The approach goes beyond the *Open Archival Information System* reference architecture by including processing and dissemination interfaces [10].

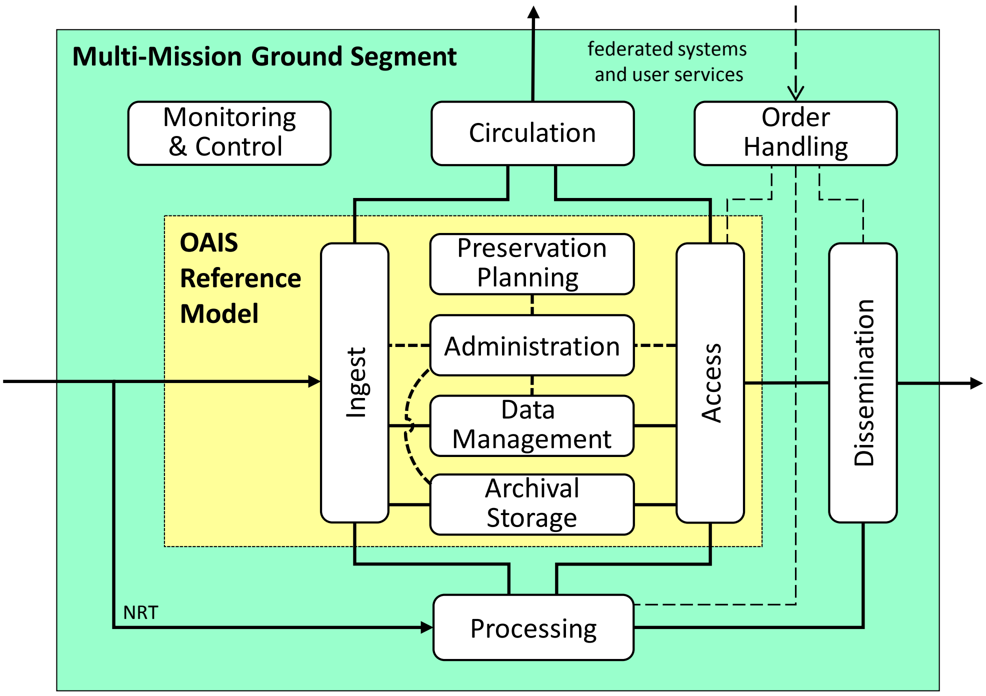

Figure 2: DIMS extended OAIS architecture

The achievements, important decisions and lessons learnt are presented in this paper.

PETABYTE ARCHIVES

Continuous evolution of media, robot technologies, and generations of archive technologies, fit with the ever growing need for more capacity. The activities performed to setup the modern Long Term Archive for Remote Sensing Data at the German Earth Observation Center are outlined in the following sections.

Data Storage Technology

Remote Sensing archives cannot be made instantly accessible with technologies like hard disks, due to wear, procurement and energy costs. This applies nowadays, as it was 20 year ago. Even though capacity has risen and the price per gigabyte has fallen steadily in an often exponential form, the space requirements have risen exponentially. Already today, current EO missions reduce the ratio of historic EO data to less the 10% of the archive size in comparison with new data, as can be seen in Figure 3; this trend persists with the upcoming EO missions of the Sentinel-Satellite era.

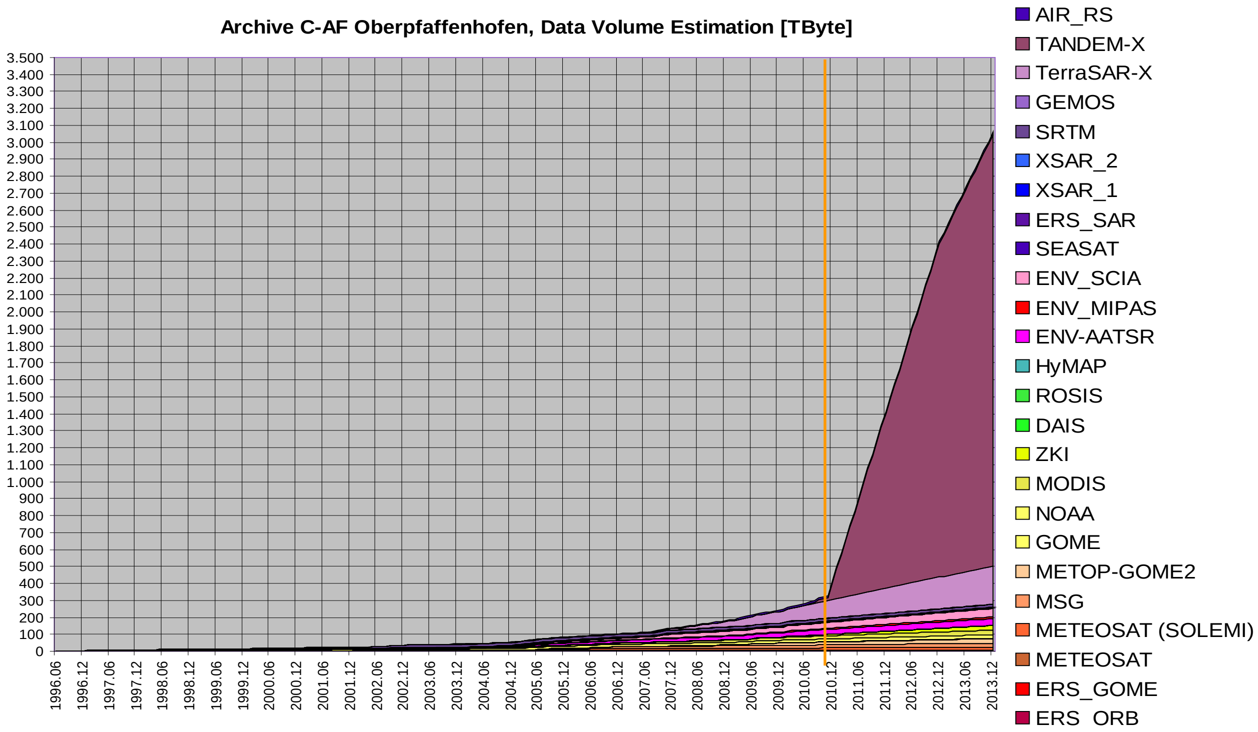

Figure 3: EOC DIMS Archive Oberpfaffenhofen

In parallel to the DIMS Archive, DLR operates a Multi-Mission Facility Infrastructure under an ESA contract [4] and [11].

Professional tapes and drives have a cost per GB near to modern terabyte hard disks, but when adding the prices of the interfaces and the cost of energy used during continuous operations, it makes hard disks clearly not a choice for long term off-line archives. On the other hand, hard disk arrays are the choice for staging caches and (browse) image servers.

The next figure shows the evolution of tape technologies. Interesting is that in the logarithmic scale the increase in capacity shows a linear aspect – also known as “Moore’s law”! The introduction of the very reliable and fast access StorageTek 9940B drives and tapes has placed this series in a leading position.

	Year	Capacity	Speed
STK T10kC	2011	5000 GB	240 MB/s
STK T10kB	2008	1000 GB	120 MB/s
STK T10000	2006	500 GB	120 MB/s
STK 9940B	2002	200 GB	30 MB/s
LTO-5	2010	1500 GB	140 MB/s
LTO-4	2007	800 GB	120 MB/s
LTO-3	2005	400 GB	80 MB/s
LTO-2	2003	200 GB	40 MB/s
LTO-1	2000	100 GB	20 MB/s
DLT-S4	2006	800 GB	60 MB/s
SDLT 600	2004	300 GB	36 MB/s
SDLT 320	2002	320 GB	16 MB/s
DLT8000	1999	40 GB	6 MB/s
DLT7000	1996	35 GB	5 MB/s
DLT4000	1994	20 GB	2 MB/s
DLT2000	1993	10 GB	1 MB/s
AIT-2	1999	50 GB	6 MB/s

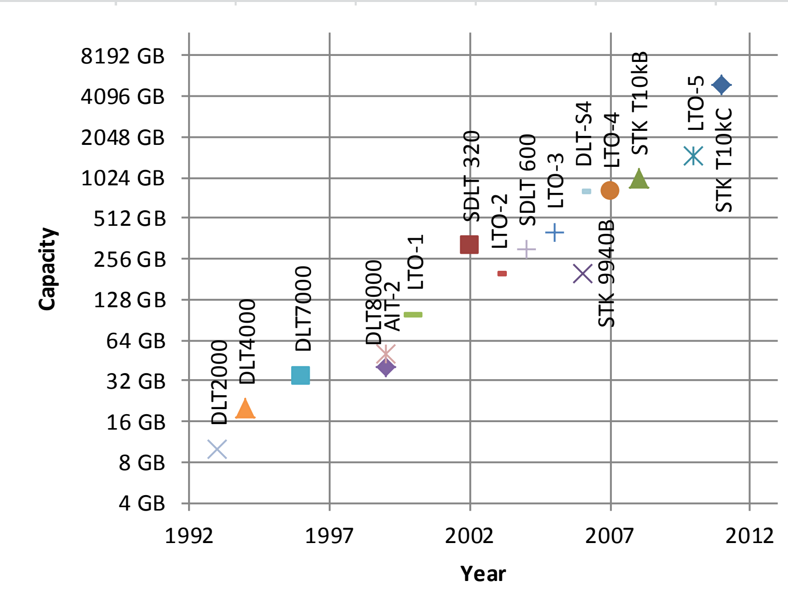

Figure 4: Evolution of tape technologies and capacities

Archive Technology

With the vision of the expected evolution in tape technology, DLR invested in the mid 90ies in a large GRAU AML/2 robot system for its Oberpfaffenhofen site with the capacity of more than 10,000 media slots.

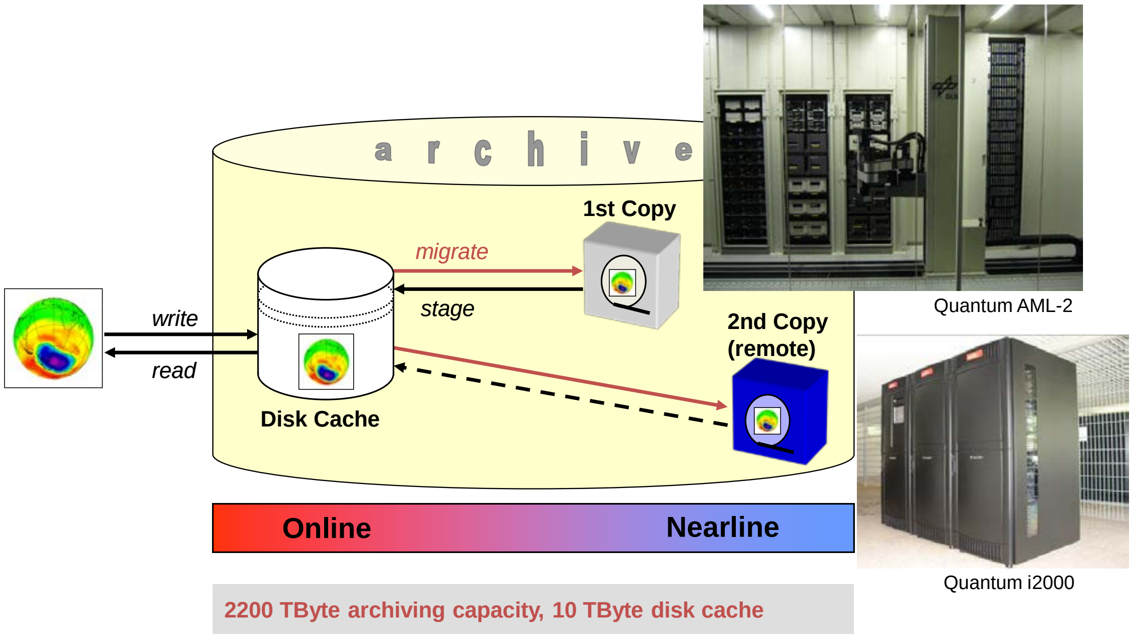

Figure 5: GRAU Robot and Archive Architecture

In the early years of operation it was not clear which tape technology would be the winner. The GRAU AML/2 robot system had the advantage that it could house containers for most of the tapes on the market (Exabyte, LTO, etc.), including off-line optical disks (MOD, CD-R, DVD, etc.). The choice of the versatile robot enabled automated migration from one tape generation to the next.

The archive at Oberpfaffenhofen holds in October 2011 about 420 terabytes of satellite data and derived products, and can be expanded to hold more than 2 Petabyte with presently available storage media. Its drives are STK 9940B, LTO-3, DLT 4000, DLT 7000, Sony AIT-2, MOD. Second copies are stored in an ADIC i2000 robot system with 700 slots for LTO3 media, which are located in another building (see Figure 5).

The file system is controlled by a Hierarchical Storage Management (HSM) system SAM-FS (Storage and Archiving Manager File System) from Sun/Oracle.

Hierarchical Storage Management Systems

The interface between the long term archive and the file system is controlled by a Hierarchical Storage Management (HSM) system. HSM turns the fast disk drives into caches for the slower mass storage devices. The initial choice was not easy, the early systems in the '90s had many restrictions (StoreNext, ADIC, AMASS, SGI DMF, SAM-FS). After an intensive analysis of the capabilities and limitations, partially with test installations, the choice was made for SAM-FS.

SAM-FS has shown to be reliable in use and daily operations. It provides a very usable operator interface (samu). The administrative overhead of the whole archive requires approximately 1/4 personnel for monitoring and preventive log analysis. The addition of file systems, archive sets, and drives are simple operations. Software upgrades have been an easy task.

Migration Planning for Long-Term Data Preservation

With such a great and well-working archive there is a tendency not to touch and change the running system. But age gnaws continuously on the robot, drives, and media; after a few years tapes show more bit errors, and replacement parts for the drives and robot become expensive or unavailable. Service, update and migration planning becomes an essential task in maintaining the LTDP system. But end-of-lifecycle helps us in this chore. For example, the need for more capacity leads to the use of new media types including new drives; this has the effect that the system undergoes an evolution and enforces us to migrate data from old media to new ones. This preempts data loss, since the digital magnetic bits recorded on the original tapes age and may become unreadable after 6 – 10 years.

Finally, the end-of-lifecycle of our central GRAU AML/2 robot system was announced for 2011. Attempting to maintain the old system would be an unaccountable risk for the archived data, which forced us renew the system. Market surveys lead us to the choice of Sun/STK SL8500. Even though we knew that it is less versatile than the old system, in lieu of possible media types, our experience in more than 20 years of operations and evolution enabled us to make this somewhat restrictive choice.

The robot and the HSM software enabled us to perform these transitions semi-automatic. Some problems stemmed from drives that were not able to read data written by other drives. Some drive reconfiguration made it possible to migrate every digital bit without a loss.

DATA AND ARCHIVING POLICY

Policies are needed when your horizon reads in decades. Costs and requirements for historical data are some of the factors that influence LTDP.

How is the data organized? What needs to be preserved? How can we read and interpret data that is 20 years of age? Many questions are best addressed by planning from the start, even though some new questions arose whilst using the system.

Harmonization of LTDP Approaches

DLR closely coordinates its LTDP approach with national and international archive operators in Earth observation (EO) and beyond. LTDP practices in Earth observation are being streamlined across the European and Canadian space agencies through the ESA LTDP working group, established in 2007, as part of the ESA Ground Station Coordination body GSCB. The working group acts through a series of workshops, documents, and studies addressing various aspects of EO data archiving and LTDP. Key documents are the 'European LTDP Common Guidelines' [6] and the 'LTDP Preserved Dataset Composition' [7]. A survey of LTDP relevant standards and procedures [8] helps ensuring that these are being observed in European EO data preservation. As a task within the data sharing initiative 'Group on Earth Observations', the LTDP working group's guidance extends beyond Europe to geospatial data archiving on a global level.

With its experience in operating a large volume EO data archive DLR actively contributes to the LTDP working group's activities and documents and thus to spreading best practice and to shaping a common LTDP approach in Earth observation. Through joint projects and exchanging archiving and preservation experiences DLR's LTDP activities reach out beyond Earth observation and Earth Science to operators of digital data archives from various disciplines such as libraries and scientific data centers. In Europe an interdisciplinary LTDP harmonization is also being fostered by the 'Alliance for Permanent Access'.

Through its varied involvement in LTDP activities DLR ensures that the LTDP practices implemented within its own archive are coordinated and in line with those of the international archiving community.

Data Formats

We know that hardware becomes obsolete within few years of time; take for example look at floppy disks, Exabyte tapes and 36mm photo film rolls. Similar trends could be expected for digital file formats. For example can you still read some archived *WordPerfect* or *FrameMaker* text files or how about TARGA or DEC CGM images?

Our systems nowadays rely on using XML for storing metadata and on JPEG, (Geo)TIFF as image formats. Can we read these files in 10 years from now? We do not have an immediate answer to this now, but DLR is keeping an eye on the evolutions in this area. We do expect a sufficiently long term software support for these formats, which enables us to timely migrate or annotate the data for our LTDP needs.

Some projects like the CASPAR digital preservation project [9] studied this area and implemented and validated techniques for capturing Representation Information and other preservation related information for content objects.

Metadata

One of the key issues for an archive is to annotate the stored information with describing metadata. Standardization activities like INSPIRE [15] and the OGC *Earth Observation Metadata profile of Observations & Measurements* [14] provide the baseline for future implementations. The metadata schema defines variants for optical, radar, atmospheric, altimetry, limb-looking and synthesis and systematic products. DLR is adopting these metadata definitions for the user services.

Processing Information

Our intention was to store the software (sources) used to create and process data. As in most systems, we only keep a reference to the software version in the metadata. The major problem with preserving SW is that it is often designed to work in with specific operating systems, programming languages and compilers, databases, network topologies, and many more environmental aspects that cannot be persisted. Also reading and adapting old code is a tedious work that comes often close to clean-room rewrites of the software. In future, comprehensive documentation of processing algorithms and software should be archived to support interpretation und understanding of the data and its origin in many years.

SW Development and QA Processes

The discipline of programmers varies as much as their personalities. Software deliveries and installation often depend on know-how of individuals. We work hard in establishing quality assured processes for the deployment and handover of SW systems to avoid problems during operations. Experience also shows that as a workaround due to lack of time, direct communication and assistance is an effective way of getting work done. Lesser quality documentation or structure results in questions when problems arise during operations or in future deployments. Stable teams providing second-level-support for the developed products have alleviated this problem in the past. But we also have been impacted by leaving personnel, resulting in gaps of knowledge.

As a result we optimize and train our people to follow the development guidelines and QA processes. We allocate at least two team members to develop and support each SW component, with several advantages:

- QA Processes establish a more constant quality, which in the long run compensates for the additional work; our processes are ISO9001 certified;
- support can be arranged during vacation or absence times;
- continuity is possible when personnel leave of are re-allocated;
- other team members can understand what has been done and how things are supposed to work (aka. where the documents are to be found, the common structure of SW and commands, etc.);

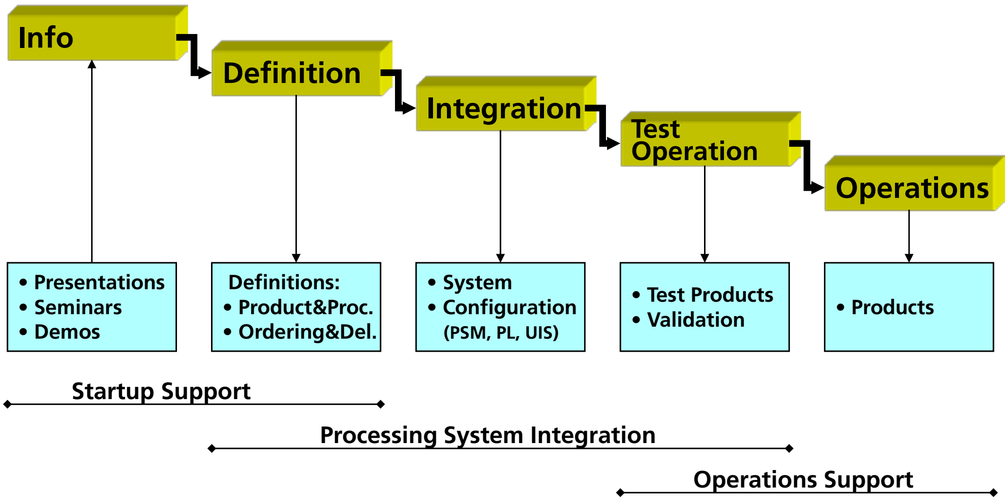

Figure 6: Integration Process Phases

A new mission can be integrated into the running multi-mission system by following a well-established development process. It starts with the scope definition, requirements collection and definition. Extensions and enhancements might require feasibility studies and trade-offs. Technology advances might require training and seminars for the involved personnel. After this, the concrete design is documented and implemented. Often the implementation in a multi-mission environment is mainly based on dataset definitions and configuration activities, but these require meticulous definition and phasing-in to avoid any disturbance of the working system. A Test Plan lays out the validation approach and specific Test Procedures are implemented to drive the acceptance tests. Finally, in a meeting the handover to the operation teams happens with a package of Configuration Items, Test Reports, and a Release Note.

OPERATIONS TEAM

The system development is only a small part of the LTDP chores. Many years of operations normally follow, requiring experts that deploy, monitor and maintain the system. Well-designed systems ease this task and motivate the operators to take over the responsibility of the system.

How is 24x7 hours of operations achieved? The archive and processing systems at the DLR Remote Sensing Data Center are designed to run in an automatic mode. Remote and on call operators are assigned to supervise the system outside of the working hours. Our current Service Level Agreements (SLA) does not require 24x7 on-site availability of the archive operators (in contrast - the satellite operations need off-hours on-site availability).

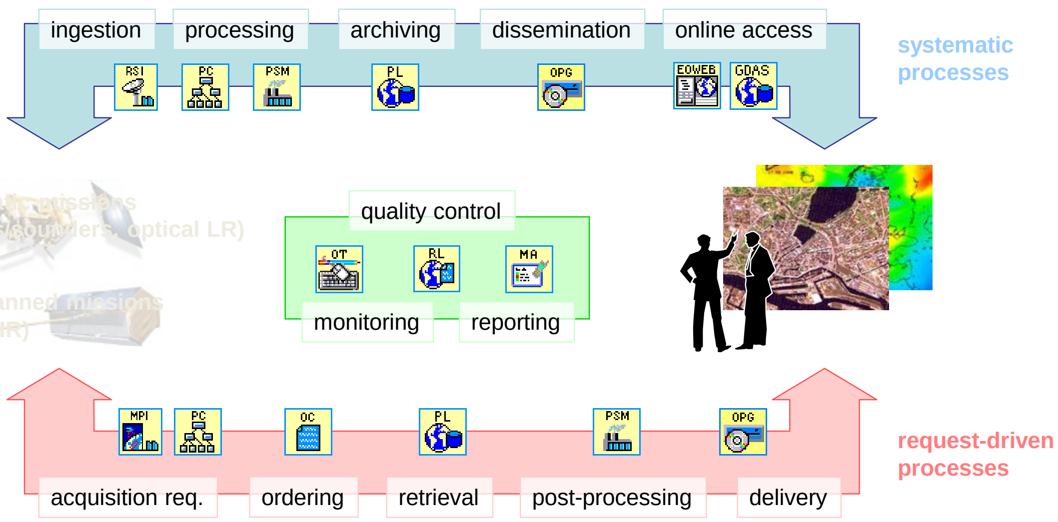

Figure 7: Satellite Product Data Ground Segment Functions

DATA AND INFORMATION MANAGEMENT SYSTEM (DIMS)

DLR has successfully established flexible and generic multi-mission system modules for automated ingestion, processing and archiving for multi-mission earth observation services. The Data Information and Management System (DIMS) was developed jointly between DLR and Werum Software & Systems AG.

DIMS faces the challenge of providing generic multi-mission system modules which can be extended and customized for upcoming EO missions. Additional functionality such as sophisticated value-adding and cross-mission production workflows, ordering of future acquisitions, data subscription, near real-time delivery and online data access services are developed and configured to meet concrete mission requirements. DIMS relies on abstract metadata, data and service models that allow identification and encapsulation of required functions, configuration of new workflows and extension of data structures, usually performed during nominal interruption-free system operation. Endowed with this flexibility, multi-mission systems like DIMS are optimally suited to provide system and payload data sustainability and operating cost savings through unified operative processes.

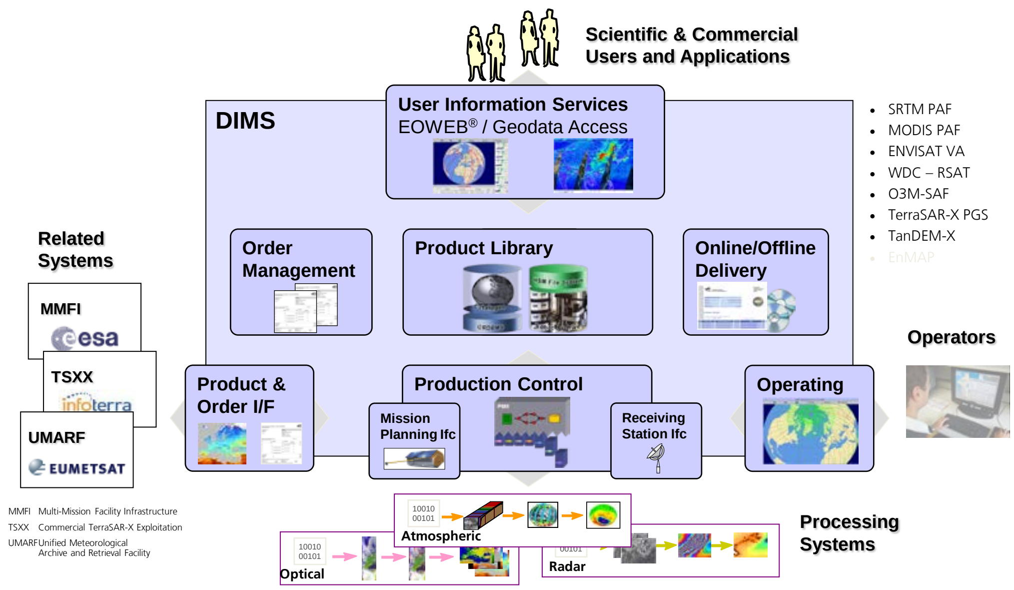

Figure 8: Multi Mission Data Information and Management System

As a requirement in all EO payload ground segments the design is driven by the following basic group of processes:

- systematic, product data driven processes
- event-based, request driven processes
- operations support processes

The systematic processes are driven by sensor data which are continuously acquired, ingested and processed. This is typical for global systematic missions continuously scanning the earth such as for low and medium resolution optical sensors and atmospheric spectrometers.

VERY HIGH DATA RATES

New satellite payload data challenge our ground segments with data rates surpassing continuous 20 MBytes/second. The configurability and the architecture of DIMS, together with current processing and network technologies enable operations beyond these rates.

As introduced in Figure 4, individual tape drives nowadays enable huge data rates. We also know that hard disks and storage arrays also can perform equally well. GBit networks seemingly also match these rates. But tests show that the problems lay hidden in the systems:

- 1 GBit copper network (1000BASE-T) utilizes Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method to the physical layer, which results in much poorer transfer rates when several computes access the archive over a switch. Solutions with TCP/IP networking over Fiber Channel (a gigabit-speed network technology primarily used for storage networking, [13]) did not work due to firmware bugs and other instabilities. Finally tests with 10 GBit networks seem to perform well for us.
- SAN (Storage Area Network) and the file systems not always perform in real/time due to caching optimizations and other operating system kernel activities. Initially ZFS seemed to be an excellent design [14], but we had severe fallbacks in performance after installing patches for the operating system. The solution was to return using the established QFS [15].

The right combination of archive hardware, HSM, disk cache system (SAN), file system, and network allows setting up an archive that enables local sustained input/output transfer rates of more than 100 Mbytes/sec. This is not sufficient for upcoming generation of EO satellites like the Sentinels, with specifications requiring sustained archive I/O-rates of more than 300 MBytes/s for the Long-term Archive. The solution currently being designed and assembled at DLR is to partition the long term archive into areas, each with own dedicated drives and disk caches. Initial tests are promising.

USER SERVICES AND SEARCH TECHNIQUES

Can you retrieve the pin in the haystack? With the ever growing amount of data, it is essential to device mechanisms that go beyond geo-temporal and metadata searches: image information mining technologies are becoming part of the archives; Google-like clients and online data access fulfill the needs of our users.

EOWEB® GeoPortal

The EOWEB® GeoPortal is the new DLR multi-mission web portal for interactive access to earth observation data. It combines the classical catalogue-and-order services with new browse-and-download features for data available via DLR's OGC services. With these new features it is possible to generate individual maps by adding, removing and altering data layers. Furthermore layers providing temporal information can be visualized for certain points in time. In addition, the download of data subsets and whole layers is also supported. The OGC services used for browsing are the WMS (incl. WMS-T), the Web Feature Service (WFS), the Web Map Tile Service (WMTS) and the Tile Map Service (TMS), whereas the download is based on OGC's WCS protocol. Finally, the modular structure of the EOWEB® GeoPortal allows the fast integration of additional services and protocols.

The EOWEB® GeoPortal is implemented using the Google Web Toolkit (GWT) [12]. For the map views OpenLayers is used [13]. The result is an interactive web application based on HTML, CSS and JavaScript. From the user perspective a standard web browser without any additional plugins is sufficient to access the EOWEB® GeoPortal. Special emphasis is put on the intuitive usability to give the user the feeling of a desktop-like application.

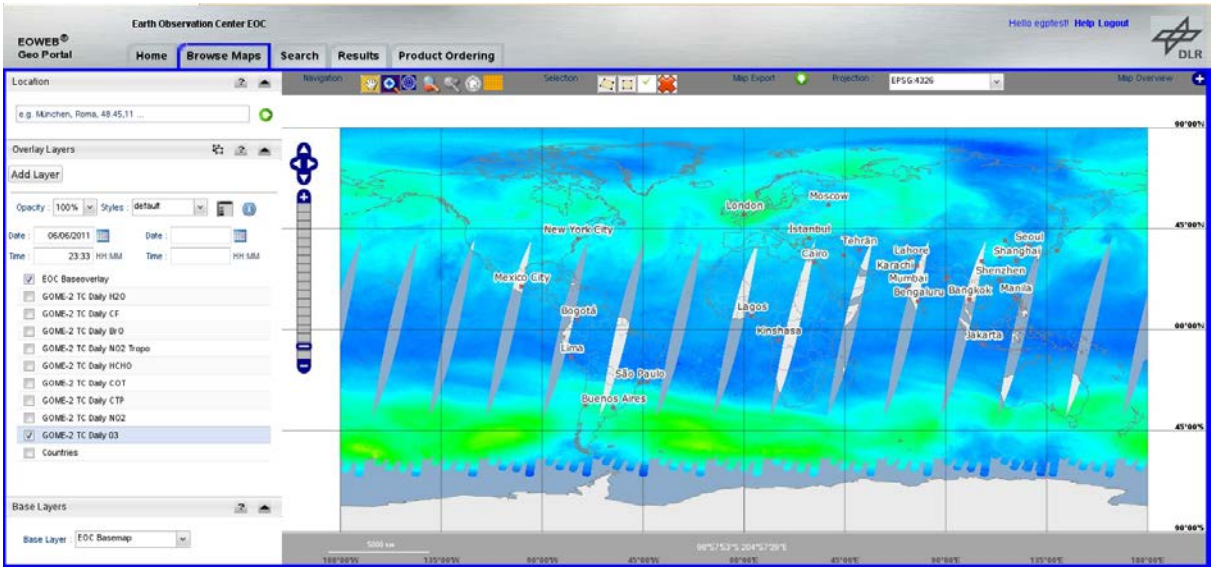

Figure 9: EOWEB® GeoPortal viewing GOME-2-derived Offline Total Column O3 Data

Image Information Mining

When users are confronted with huge datasets, in many scenarios it will be very difficult to identify the required data. Google like systems have demonstrated that finding textual information in large systems is possible. Nevertheless the precision of search results can be improved greatly.

DLR has researched in the past years Image Information Mining (IIM) approaches to implement content based search for Earth Observation data [12]. A recent project titled *Earth Observation Image Librarian* (EOLib) has started with the purpose to setup an operational IIM system. EOLib will utilize Earth Observation (EO) product content and information usually hidden in raster data, image time series and metadata to enable content-based search in very large archives of high resolution EO data.

CONCLUSION

The powerful and centralized archive at the DLR Earth Observation Center has proven its stability and flexibility to allow Long Term Data Preservation over more than 20 years.

- The vision, system choice and software development of the DIMS environment were key elements to this success.
- SAM-FS has been a good choice for the Hierarchical Storage Management system.
- To prevent data loss a continuous sequence of data and media migration is necessary every 5 to 6 years.
- System maintenance and evolution is indispensable to keep up with the technology pace and to increase the storage capacity to fit the ever growing requirements.
- In 2012 input/output data rates have grown to be beyond 100 MBytes/s, but the disk drives and networks have also grown. Careful system design avoiding bottlenecks are indispensable to be able to provide un-interrupted services.
- New content-based search technologies will enable users to find the desirable datasets in the huge archives.

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Christoph Reck was born in Puerto Rico, USA in 1963, graduated from the Technical University of Munich in 1988 with a Diploma in electrical engineering. His early career started with contributions at DLR to several space and satellite missions (LVMD/D2-Spacelab, ERS-1/2, HRSC/Mars'96/ MarsExpress) specialized in HW design, control, and testing interfaces. In years thereafter, lead the design of the ISIS graphical user interface, web user interfaces (INFEO, MUIS), and the Operating Tool of DIMS. As system engineer of the FEOMI project he backed ESA in deploying a multi-mission infrastructure at several European centres. In the past years he worked as project manager for the ESA Distributed Processing Capacity Study, HMA multi-mission implementation project, interfacing GMES GSCDA contributing missions, and writing specifications for the ESA next generation user services for Earth Observation (ngEO). Recent work started for implementation of operational Image Information Mining user services to DIMS.

Stephan Kiemle was born in Munich, Germany in 1966. He received the Diploma degree in Computer Science from the Technical University of Munich (TUM), Munich, Germany, in 1995. Since 1995, he has been with the German Remote Sensing Data Center (DFD), German Aerospace Center (DLR), where he started as software developer for the Interactive Satellite Information System ISIS. In 1997, this work merged into the development of DFD's multi-mission earth observation data system, the Data and Information Management System (DIMS), where he was responsible for the Product Library. Since 2003 he leads the DIMS development team and works as system engineer and project manager for a couple of earth observation payload ground segment and infrastructure projects.

Eberhard Mikusch was born in Kaufbeuren, Germany, in 1961. He earned his Diploma in computer science from the University of Applied Sciences in Munich, Germany, in 1983. His work at the German Aerospace Center (DLR) involved developments of distributed ground segments of various challenging space projects. From 1983 to 1987 he was development engineer for the Electrical Ground Support Environment and designer of the DLR's image processing system for the Halley Multicolour Camera (HMC) of the European Giotto Mission. From 1987 to 1992 he was system engineer responsible for the design of the distributed Ground Support Program Equipment (GSPE) for the telemedicine experiment Anthrorack in the framework of the German D2 Spacelab Mission. In the years 1993 to 1997 he jointly designed and developed the ozone retrieval processor for the Global Ozone Monitoring Experiment (GOME) onboard the ERS-2 satellite. From 1996 to 2003 he was leading the development team establishing the multi-mission Data and Information Management System (DIMS) for several ground segments (incl. TerraSAR-X). Since 2004 he is head of the information technology department of DLR's German Remote Sensing Data Center (DFD).

Katrin Molch holds a Master's degree ('97) in Geosciences acquired in Germany and the U.S.A. For over ten years she has been working as a remote sensing scientist with Canadian and European Earth observation research organizations and in industry. Her scientific focus is on exploiting radar satellite imagery for geological and urban applications. She has developed and given several training courses on satellite image exploitation and radar interferometry to international civilian and military clients. Since 2009 she is the Earth observation data librarian of the German Remote Sensing Data Center (DFD) of DLR. Leading the User Services team, she is working towards improving accessibility to the organization's Earth observation data holdings and increasing their use by a wider customer base.

Wilhelm Wildegger graduated with an Electrical Engineering (Data Processing) diploma from the Technical University of Munich in 1979. He worked at DLR on hardware and firmware development amongst others for satellite receiving stations and ground segments of the German Spacelab Missions FSLP and D-1. He was Project Leader for the requirement analysis, design, implementation and operation of an *Advanced Electrical Ground Support Equipment* for the ESA payload element 'Anthrorack' flown on the German Spacelab Mission D-2. He is leading the 'National Remote Sensing Data Library' project, which includes the development and operation of the Data and Information Management System (DIMS) and the integration of processing systems into DIMS. He is the IT-Manager for the Applied Remote Sensing Cluster (C-AF) and is responsible for procurement, integration and operation of the IT infrastructure of the institutes.