Adding a Recurrent Satellite to an Existing Operational System

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Metop-A, Europe's first polar-orbiting meteorological satellite lifted into orbit from the Baikonur Cosmodrome in Kazakhstan atop a Soyuz launcher on 19 October 2006, marking a new era of weather and climate monitoring for Europe. Metop-A will shortly be joined in orbit by Metop-B, scheduled for launch by another Soyuz rocket also from Baikonur in May 2012. Preparing for the launch of Metop-A proved to be a challenge for EUMETSAT, especially in the area of readying the EPS ground system - a system originally designed to simultaneously operate two satellites but only validated at the time to support one. Operations preparation activities for Metop-B began in 2009, starting with the evolution and revalidation of the ground system to support two separate spacecraft data streams. Thereafter, the EPS/Metop operations concept was modified to operate two satellites via a single operational ground segment with a single unified operations team. Key to this process was the definition and implementation of the operations concept for a dual-satellite system. This included defining the most effective approach to handle satellite and system procedure modifications, including taking maximum advantage of interpreted procedures (using STOL language) for spacecraft procedures. The definition and validation of the operations concept led naturally into the successful development and validation of the required operations procedures and databases, the training of the operations team and the completion of the operational rehearsals prior to launch. All performed while ensuring continuity of the operational services from the Metop-A satellite to the EUMETSAT user community. This paper will also present the lessons learned from the Metop-B preparations that may be usefully applied in the lead up to the introduction of the third Metop satellite.

I. Introduction

EUMETSAT‟s mission is the exploitation of Earth-observation satellites to support the fields of operational meteorology, climatology and oceanography. Among the many factors that bear consideration when defining such a mission, two in particular have a particular importance that is reflected in the manner with which the mission is implemented.

Firstly, due to the nature of meteorological, climatological and oceanographic studies, long-term continuity of operational services is essential to provide the user community with consistent datasets over extended timescales. This implies an overall mission lifetime significantly greater than those normally expected for missions primarily oriented towards research and technology demonstration.

Secondly, the large financial investment required to develop and deploy such Earth-observation systems – both space and ground segments – means that it is significantly cheaper overall to develop larger systems with longer lifetimes than smaller systems with shorter lifetimes.

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To address these two fundamental issues, EUMETSAT operational programs have been defined with multiple satellites ensuring continuity of the space segment through recurrence – the periodic replacement of an operational satellite with an equivalent to ensure a total mission lifetime in excess of that possible from a single satellite.

II. The Concept of Recurrence

A. Recurrence at EUMETSAT

Recurrence has been a fundamental aspect of EUMETSAT operational programs from the very beginning of the Organisation and, even earlier, from the beginning of satellite-based meteorological observation in Europe. Indeed, EUMETSAT was founded, in part, to ensure the continuity of operational services to users through the use of recurrence.

Recurrence occurred six times during the lifetime of the Meteosat First Generation (MFG) program, with two instances under the responsibility of EUMETSAT. In the Meteosat Second Generation (MSG) program, there has already been one instance of recurrence and will occur a further two times up to and including the transition of MSG operational services to Meteosat-11.

Preparations are at an advanced stage for the launches of Meteosat-10 and Metop-B, and the recurrent transitions that will occur once each is declared operational.

To add a further measure of complexity, the launches of Meteosat-10 and Metop-B will occur in close proximity to each other, with only a minimal time interval between the two. Preparations for, and the execution of, parallel recurrence in these two programs will result in a particularly intense period of activities for those in the EUMETSAT Operations management and in the Operations Team supporting multi-mission facilities.

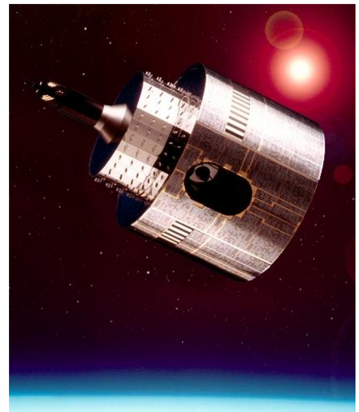

Figure 1. There have been six recurrent transitions in the lifetime of the MFG program

1. Recurrence in Geostationary Programs

The first EUMETSAT program to adopt a recurrent approach was the MFG series of geostationary satellites. This program was initially developed and operated by the European Space Agency (ESA), with the first MFG satellite (Meteosat-1) launched in 1977 and followed by Meteosats-2, -3, -4 and -5 over the next eighteen years. In 1995, EUMETSAT assumed operational control of Meteosat-5 and continued the unbroken operational coverage begun with Meteosat-2 by launching Meteosat-6 in 1996. The last of the MFG series – Meteosat-7 – was launched in 1997 and will likely remain in operational use by EUMETSAT until 2017, some forty years after the MFG series first arrived on-orbit. In the intervening years, the MFG satellites combined to provide near-continuous services to European and global users of meteorological and climatological data.

The second generation of Meteosat geostationary satellites (MSG) entered service in 2002 with the launch of Meteosat-8, followed by Meteosat-9 in 2005. This program will, with a further two satellites, span the period from 2002 to well into the third decade of the 21st century, at which time it will be superseded in this mission by the Meteosat Third Generation (MTG) system.

2. Recurrence in Polar Programs

In polar orbit, EUMETSAT operates the Metop-A satellite as the first element of the space segment for the EUMETSAT Polar System (EPS). At the time of writing this paper, Metop-B is nearing readiness to launch in mid-2012 to replace Metop-A in a recurrent transition to become the prime operational polar-orbiting satellite. Metop-B will be followed in the 2017 timeframe by Metop-C as the final component of the EPS space segment. Ultimately, EPS will be superseded by the EPS Second Generation (EPS-SG) program around the end of the decade.

Relating to oceanography services, EUMETSAT processes mission data from Jason/OSTM, although without operating the space segment. Services currently derived from Jason-2 will transition to Jason-3 after this newer satellite is launched in 2014.

Figure 3. EPS services currently supported by Metop-A will transition to Metop-B after it is launched in 2012.

3. Future programs at EUMETSAT

Future EUMETSAT programs will continue to include recurrence as an integral component in the mission design. The MTG geostationary program‟s space segment includes three imaging satellites and two sounding satellites, with only one of each type designated as the prime operational satellite at any one time. In polar orbit, the Sentinel-3 mission is currently under development and includes three satellites to be launched consecutively in order to support the associated operational services. Recurrence will also be a fundamental aspect of the EPS-SG program.

It is clearly a critical capability for EUMETSAT to be able to introduce a recurrent satellite to an existing operational program and smoothly transition operational services to that new asset. Such a transition may seem straight-forward at first glance, but requires careful planning and implementation in order to be successful.

In some cases, introducing a new satellite may place new or originally-unforeseen demands and constraints on the overall system, especially the ground segment, which were not previously relevant. In the following sections, these considerations will be discussed in detail, with reference made to previous and future recurrence in EUMETSAT operational programs.

B. Recurrence Compared to Evolutionary and Revolutionary Change

Recurrence places different, and usually lesser, strain on an organisation such as EUMETSAT, when compared with the introduction of entirely new operational systems.

1. Evolutionary Change

Where the introduction of a new system represents an evolutionary change relative to the design and operation of an existing system, such as the transition from MFG to MSG, a significant amount of operational knowledge from the former program will remain valid for the latter.

In the example given, both MFG and MSG satellites are spin-stabilised geostationary satellites that acquire data in a variety of frequency bands, and support retransmission of their own and other data. While MSG is a significantly more capable design, and had entirely new systems to implement the space and ground segments, there was no revolutionary change in mission between the two programs.

2. Revolutionary Change

In contrast, the introduction of a new system which represents a revolutionary change – performing an entirely new mission or performing an existing mission but in a radically different way – can often permit only a limited amount of operational knowledge to be carried over into the new program.

The introduction of EPS was EUMETSAT‟s first polar-orbiting mission, requiring expertise of a radically different operations concept compared to the geostationary programs, and representing a revolutionary change in the organisation‟s mission. Similarly, the MTG program will take over from MSG in the geostationary mission towards the end of this decade, but will implement this in a very different manner, utilizing two co-located three-axis stabilised MTG satellites to replace the single spin-stabilised MSG satellite.

Recurrence events occur more frequently than the introduction of new programs. While new programs imply a significantly greater change to operational knowledge and capabilities than for recurrence, the higher frequency of recurrence events must be taken into account as the cumulative change in operational knowledge can still be significant.

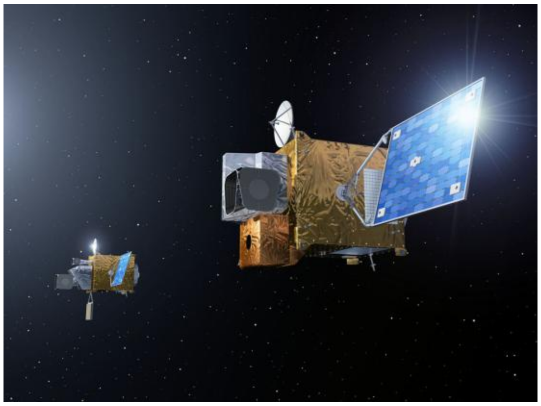

Figure 4. The start of MTG operations will represent a revolutionary change in the execution of geostationary satellite operations for EUMETSAT from the MFG/MSG era of spin-stabilised satellites.

The following sections will discuss the specific issues of spacecraft, system and product processing operations in relation to the implementation of recurrence in the EPS Program relating to the introduction of Metop-B.

III. Spacecraft Operations

The most critical aspect when adding a recurring satellite to a system is ensuring that there is no negative impact on spacecraft health and safety or operational services. There is also a desire to maintain staffing levels within the Flight Control Team, both to avoid a direct increase in financial expenditure and the additional organization and coordination overhead inherent in larger teams. Throughout the routine operations phase on Metop-A, there has been a significant amount of effort focusing on improvements to spacecraft operations which are necessary to meet these objectives.

This section focuses on some of the improvements to efficiency and robustness which have been made to allow Metop-B to be introduced into the system with minimal impact to Flight Control Team workload. To offset the increased workload which cannot be avoided with two spacecraft in the system, some of these improvements have more than compensated for an extra spacecraft. In all cases, the improvements are also applicable to future recurrence within EPS – i.e. the launch of Metop-C.

A. Improving Overall Commanding Chain Robustness

In order to maintain operational services, the Metop spacecraft must be continuously commanded to control routine instrument calibrations, dumps of recorded science data over the CDA, enabling and disabling of the local mission services and uplink of critical AOCS commands.

Routine commanding is handled by an automated chain which gives 36 hours of onboard autonomy. Procedure requests are sent from the Mission Planning Facility (MPF) according to a predefined schedule to the Procedure Initiator (PI) at onboard execution time -37 hours. A single instance of both MPF and PI are used to control the entire system, including all spacecraft and ground. The PI then instructs the appropriate streams to run procedures which results in one or more commands being loaded onto the ground queues. Commands from the ground queue are then uplinked at each ground station contact and stored in on board queues until their execution time is reached. This flow is illustrated in Figure 5 below.

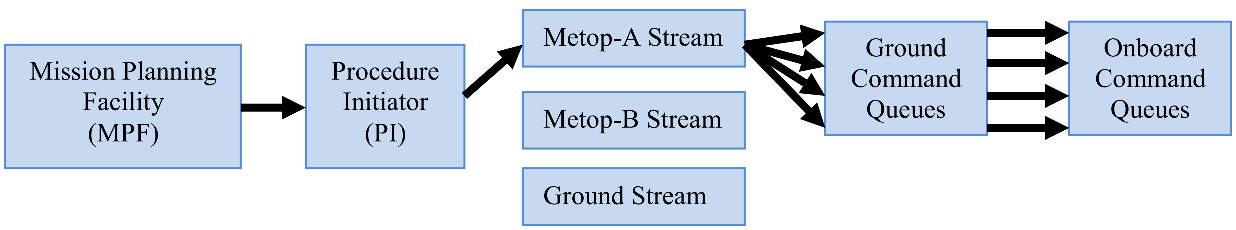

Figure 5. Routine Command Flow in the EPS Ground Segment

Under normal circumstances, this system is very reliable; however problems occur when manual intervention is required due a spacecraft server restart emptying to ground queues or an onboard anomaly which empties the onboard queues for example. In such cases, it is often necessary to re-enable already executed procedures on the PI to re-uplink commands. The onboard buffer models reliably display the contents of the various onboard queues, however this is done in chronological command execution time, so commands from various operations or procedures become interweaved and it becomes very difficult to get a clear picture of which procedures need to be resent from the PI. At best, this places an unnecessary workload on controllers and at worst, human error has occasionally resulted in omission of commands which has lead to data outages. Early system level simulations and rehearsals showed that two satellites being operated in parallel exacerbated the situation as expected.

One possible solution to this would have been introducing feedback from the on-board buffer models to the PI, so that procedures which have executed but do not have all their commands in the expected on board queues would be flagged. However, this would require a major evolution to critical elements within the system which was deemed too risky. Instead, it was decided to introduce an independent Operations Checker GUI to the system. The aim of this GUI is to provide an "at a glance" synthesis of the status of all routine operations required to maintain satellite health and operational services, and also generate a system level warning in case of problems. Implementation of such a solution within EPS is possible because;

- All such operations are repeated either according to flight dynamics events (e.g. ascending node crossing, ground station AOS, solar zenith angle , etc), the 29 day ground track repeat cycle or some combination of calendar and flight dynamics events (e.g. the first ascending node crossing after 10 GMT on Tuesdays),
- A pre-existing SQL database contains all flight dynamics events used in planning,
- A pre-existing SQL database contains a complete history of all telecommands, including their COP-1 CV and deletion status which determine whether they are onboard the spacecraft.

The logic to define everything about the operations to be displayed in the GUI is defined in a flexible xml format which can be updated to allow for evolutions in operations.

The overall layout of the GUI is shown in Figure 6 below. The GUI represents the status in a clear tabular form with orbits represented by rows and operations by columns. In live view, the second row is always the current orbit and the GUI will show the status of operations 37 hours into the future. In case any operations are in partial failure with less than 6 hours to expected execution time, the GUI will actively alert operators by sending an event to the Generic Event Monitoring System (GEMS) within the EPS GS, allowing mitigating action to be taken.

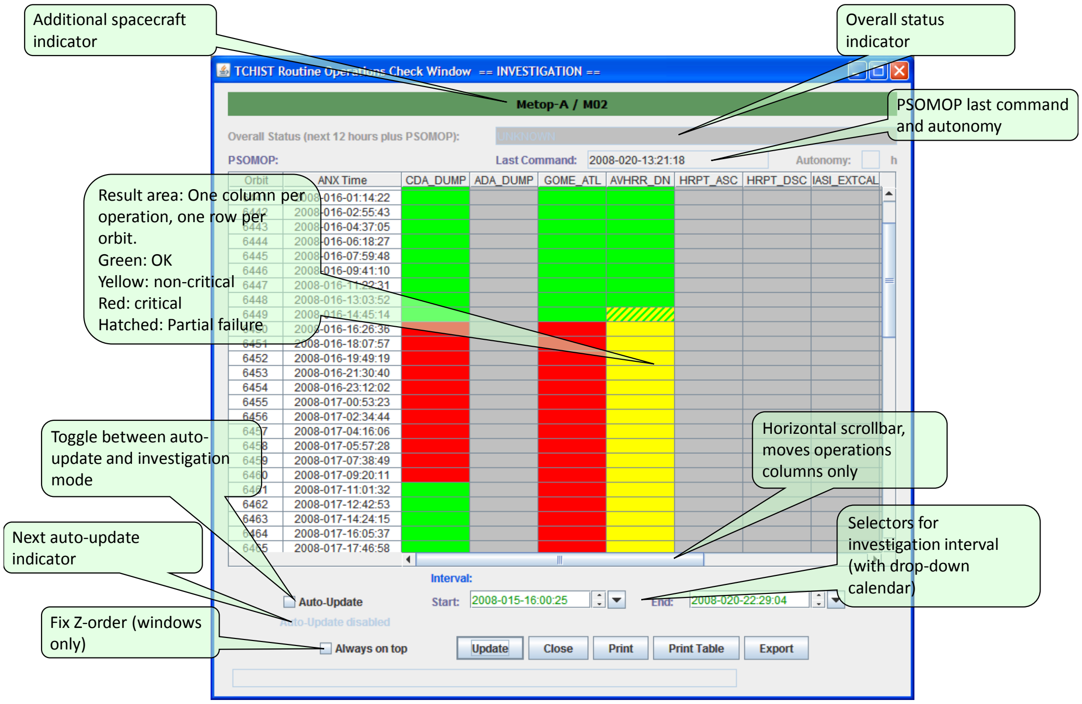

Figure 6. Routine Operations Checker GUI

The operations checker has been tested during Metop-B IV&V activities as well as during Metop-A routine operations where it has been demonstrated to improve robustness of the overall commanding chain as well as alleviate undue stress during anomaly recoveries.

B. Handling Flight Model Differences in Flight Control Procedures

Even though all Metop spacecraft are intended to be identical, there are flight model differences which need to be considered in operations. The nature of the EPOCH control system and the Spacecraft Test and Operations Language (STOL) in which FCPs are coded allows a common procedure set to control all spacecraft and handle any flight model differences safely and reliably. Having a single set of FCPs for all spacecraft reduces the maintenance and configuration overhead compared with maintaining a distinct set of FCPs for each spacecraft.

This section describes the types of flight model differences which need to be handled by the system and how the STOL FCPs and the EPOCH control system are used to this effect. The aim is always to maintain as linear a procedure flow as possible and push the burden of handling flight model differences to the lowest level function possible, i.e. the order of preference is the MCS/database, followed by automated STOL FCPs, followed by the Manual FCPs which are used to instruct the controller which STOL FCPs to run for a given operation. Shifting the burden to lower level functions in this way allows all the decision making to be thoroughly tested in a validation environment and reduces the risk of human run-time error.

1. Calibration Differences

Differences in calibration curves for a given telemetry point across different flight models are handled by the Spacecraft Database. For example, an FCP may perform a thermal pre-check before issuing a command. In such cases, pre-checks are always in terms of physical temperatures measured by thermistors, rather than their raw readouts. Any difference in the calibrations of thermistors across flight models is therefore transparent to FCPs. Similarly, when limits for autonomous on-board monitoring of parameters are loaded via telecommand, physical units are always used and the Database and MCS convert these to the appropriate raw values when the telecommand packet is constructed.

2. Data Value Differences

When activating subsystems on the Metop spacecraft from a cold restart, it is often necessary to load tables of parameters via dedicated commands. The values of parameters to be loaded usually depend on the current in-flight performance of that subsystem, so vary between flight models.

The STOL language allows child procedures to be called, and the values of local variables can be extracted from those child procedures. The contents of commands can then be separated from their upload mechanism using a type of child procedure known within the EPS Ground System as a datastore, which is a simple procedure responsible for assigning values to variables. The STOL language also allows the value of any telemetry parameter to be assigned to a variable which can then be used in any string substitution. This allows a single, linear FCP to handle the upload of flight model dependant data to multiple spacecraft. In the example STOL code below, the spacecraft identifier is read from telemetry and assigned to a local variable, SC_ID. This is then used in a string substitution to call the appropriate datastore file which contains the values of the command parameters to be uploaded, either MD***A***_GOME_FPA_DEFAULT.dts, MD***B***_GOME_FPA_DEFAULT.dts or MD***C***_GOME_FPA_DEFAULT.dts for Metop-A, B & C respectively.

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…..

#Read the calibrated Spacecraft ID from Telemetry Parameter "TMZALI" (A, B or C)
SC_ID = STATE(TMZALI)

#Call Datastore to retrieve current default channel separation pixel boundaries for focal plane assemblies
START MD${SC_ID}_GOME_FPA_DEFAULT.dts (&BAND1A, &BAND1B, &BAND2A, &BAND2B)

#Send command to uplink the default channel separation values
MCMD SEND OOA021 B1A=${BAND1A} B1B=${BAND1B} B2A=${BAND2A} B2B=${BAND2B}
…..
```

3. Functional Differences

There are some cases where the FCP required to achieve a certain objective must be functionally different between flight models. How these differences are handled depends on the extent to which they impact the operation; however the goal is to make the differences transparent at the level of planning operations by placing the logic within automated STOL FCPs if possible. In this example, we consider patches which need to be applied to Metop-A RAM during subsystem activation in-flight, but which have been retrospectively incorporated into the EEPROM of Metop B & C before their launch.

- If a small patch of a couple of 16-bit words is needed during the activation of a subsystem on one flight model only, a generic STOL FCP is used. STOL FCPs use the standard „IF" statement to check the spacecraft identifier and send or omit additional commands depending on the spacecraft being commanded.
- If a large patch is required due to software recompilation for example, the application of this patch may take several commanding passes. This makes the operation fundamentally different at the planning level and so differences can no longer be masked within the logic of a generic STOL FCP. In this case a flight model specific STOL FCP must be developed and execution of the operation requires different planning. Again, the spacecraft identifier can be used in conjunction with an „IF" statement to ensure that the STOL FCP will „bin out" if accidentally activated for the wrong spacecraft.

In all cases, updates to procedures have been applied on an as-needed/opportunity basis. This has allowed all modifications to be incrementally tested and validated under nominal operations processes, rather than held back for testing during IV&V with a bulk release to the operational system. The advantage to this approach is the reduced risk associated with small, incremental updates.

C. Offline Monitoring and Reporting

In orbit assets are the most critical, costly and irreplaceable component in any system which uses them, so offline monitoring and reporting of spacecraft health is an essential activity during the routine operations phase.

During the Metop-A routine operations phase, it was found that this activity was causing a significant workload for the operations team, despite some efforts at automation. In particular, telemetry retrieval times became increasingly problematic with mission life and much of the routine analysis involved manually collecting data from several sources via GUIs, then importing the resulting text files into analysis tools such as excel. Moreover, it was recognized that the workload caused by this activity would increase proportionally with the number of operational satellites. In order to maintain capabilities without expanding the team, significant improvements in this area had to be realized before Metop-B launch.

Within the EPS system at Eumetsat, there has been a move towards offline monitoring databases, especially within the product processing teams. A lot of this work has been consolidated into the ARGUS project which provides;

- Monitored, buffered, near real time data feeds from the operational ground segments
- Powerful, scalable database servers
- Database back up services
- Network access to desktop machines within Eumetsat.

Taking advantage of this available infrastructure and lessons learned from several ad-hoc prototypes, the Component Health Assessment and Reporting Tool (CHART) was developed to cover the off line monitoring and reporting of all Metop spacecraft. At the centre of CHART is an Oracle database containing multiple tables of raw spacecraft telemetry, results of any routine periodic or a-periodic computations, periodic statistics of all time series data and auxiliary data such as flight dynamics events, telecommand history etc. Various applications have then been developed to plug into this database, covering;

- Ad-hoc retrievals and archive browsing via license free GUI. Browsing is achieved by the ability to enable automatic sub-sampling which can switch between periodic statistics and „all-samples" as necessary.
- Powerful analysis is handled via MATLAB with the help of the Database Toolpack, allowing retrieval results to be assigned to workspace variables.
- Schedule driven generation of customizable reports with an HTML editor allowing annotation by subsystem experts.

The modularity of database design has allowed iterative and incremental development. The advantage of this is that any investment in ingesting a new data source or defining new automated routine analysis is quickly recovered and development can fit around other activities to fill troughs in the workload of the team.

The database and surrounding infrastructure is specifically designed to accommodate planned recurring satellites within a program and also be largely replicated to cover other missions within Eumetsat, meaning CHART can offer significant overall cost savings both through economies of scale and through its performance.

IV. Systems and System Operations

When discussing the implementation and implications of recurrence in the following section, examples are drawn from the recent activity within EUMETSAT in preparation for the launch of Metop-B, and the forthcoming recurrent transition.

A. Systems and Recurrence

Recurrence typically has an impact on most aspects of the operational system, ranging from the monitoring and control function to the ground stations, operations team and procedures. In some cases, it is simply necessary to introduce a second equivalent configuration when adding a recurrent satellite, while in others previously sufficient configurations must be modified to remove a generic implementation.

The impact of recurrence is further affected by the verification and validation activities performed earlier in the program lifetime. If the planned recurrence was foreseen and fully verified and validated in the past, then a lower level of preparatory testing may be acceptable. However, if the recurrence was not fully verified and validated previously, or if the recurrence was even not foreseen to occur in the planned form, then a significant verification and validation effort may be required to ensure that the operational system is ready.

B. Maintaining Operational Services

When introducing a recurrent satellite to a system already supporting operational services, it is essential to implement this recurrence with minimal impact – preferably none – on the provision of these operational services to users. Achieving this requires careful planning and implementation of system modifications and subsequent testing activities. In some cases, it is unavoidable that elements used for the provision of operational services will require modification while in use, although system redundancy and normal maintenance processes should provide a mechanism for updates under such circumstances that prevent unforeseen impact on operations.

Figure 7. Satellite operations are performed from the EUMETSAT Mission Control Centre in Darmstadt, Germany.

1. Systems with Multiple Environments

Key to achieving this is the use of separated environments for the preparation, implementation and testing of system modifications required for recurrence. Wherever possible, operational and verification7validation environments should be separated while retaining sufficient representability to ensure that the outcome of such activities remains valid for subsequent implementation on the operational systems.

In the EPS System, three distinct environments have been created that allow the majority of system functions to be prepared without risk to the routine provision of operational services. Each environment is assigned a dedicated purpose as indicated below:

1) Ground Segment-1 (GS-1) is the prime operational ground segment used to operate the in-orbit Metop satellites, control the Svalbard ground stations, and perform product generation and archiving in support of the EPS operational services. System and operational modifications are only deployed on GS-1 once they have been operationally validated on GS-2.
2) Ground Segment-2 (GS-2) is the validation ground segment and a backup to the prime operational ground segment. GS-2 is used to perform operational validation of new operations procedures, facility software and hardware, communications configurations and operational products. System and operational modifications are only deployed on GS-2 once they have been developed and functionally verified on GS-3. With the exception of specific items under validation, GS-2 is maintained in a configuration highly-representative of GS-1. GS-2 is also used as the principal environment for pre-launch Satellite Verification Testing (SVT) activities and operational rehearsals.
3) Ground Segment-3 (GS-3) is the development and functional verification ground segment used to prepare and develop system and operational changes. This environment is a development and test area where the deployed configuration is subject to frequent change and is therefore not generally representative of GS-1. To prevent inadvertent operations of operational elements during test activities, this environment is extensively isolated from both external system interfaces and GS-1/-2.

All three ground segments are subject to strict configuration control, with formal verification or validation test reports and engineering change tasks requiring management approval before a modification tested on GS-3 can be transferred to GS-2, or from GS-2 to GS-1. By carefully controlling the flow of system modifications between ground segments, system modifications are thoroughly tested and their impacts well understood before they can impact on the operational services supported by the prime operational ground segment.

2. Exceptions to the Rule

However, in all rules there are exceptions. There are a small number of EPS System facilities shared between GS-1 and GS-2 as Central Site (CS) elements, such as the Generic File Transfer facility (GFT), although separate GS-3 equivalents exist. It is therefore not possible to maintain the same GS-3 → GS-2 → GS-1 flow of changes with two built-in quality gates, instead following a reduced path from GS-3 → CS, giving a shortened process for change implementation and test.

Additionally, there are also some aspects of the system where there is no separate test environment. The communications system does not have a dedicated test lab where configuration changes can be modeled and validated before deployment on the operational system. Creating such a test environment would require duplicating the systems currently made available by external service providers, representing a cost and complexity overhead that could not be justified.

Both of these exceptions require careful management to ensure that there is no inadvertent effect on operational systems from the introduction of system changes.

C. Implementing, Verifying and Validating System Changes

Consider EPS System preparations for the launch of Metop-B. During preparations for Metop-A, and in order to be ready in time for the planned launch, it was decided to complete validation of the EPS System to a level sufficient to demonstrate operational readiness to support a single Metop satellite. Therefore, before Metop-B operations preparation could begin in earnest, the re-verification of the entire EPS System for dual-satellite operations was necessary.

1. System modifications for Metop-B

In some cases, this was a simple case of duplicating Metop-A aspects of the system with equivalent ones for Metop-B, while in others, a single generic Metop configuration had been adopted that had to be separated into distinct Metop-A and Metop-B configurations. Where a single generic Metop configuration had been adopted, the first priority was to create and validate a Metop-A configuration to allow this to be operationally used. Once this had been done, the newly-defined Metop-B configuration was then validated.

The following systems required update to support the recurrent transition from Metop-A to Metop-B:

1) Mission Control Facility (MCF) – combining the monitoring and control, flight dynamics and mission planning functions, this facility had to be re-verified at a functional level for dual-Metop operations and then operationally re-validated using updated operations procedures against the Satellite Simulator. Metop-B related changes to the MCF included the introduction of a Metop-B context for flight dynamics product generation and distribution, a Metop-B set of rules for the scheduling of operations in Mission Planning, and the configuration of Metop-B streams for S-band TM/TC and X-band data processing.
2) Ground stations – each satellite is supported by a dedicated configuration validated to ensure that S- and X-band sub-system configurations, antenna pointing information, and compatibility with the interface to the MCF were all functioning correctly. Prior to the start of Metop-B preparations, the EPS ground stations were defined with a single generic Metop configuration, which had to be separated into two distinct Metop-A and Metop-B configurations then individually validated.
3) System communications – in addition to the relatively simple configuration changes required to identify and manage Metop-B comms traffic, communications between the EPS ground stations in Svalbard, Norway and the EPS Central Site in Darmstadt, Germany required upgrade. These were originally by means of a path-redundant fiber-optic link, backed up by a satellite-link alternate. While additional capacity on the fiber-optic link could be easily procured to support both Metop-A and Metop-B traffic in parallel, the satellite link could not be upgraded without a prohibitive cost impact. An alternate solution for the backup link was implemented via Gigabit European Advanced Network Technology (GEANT) for all traffic, while the satellite was link downgraded to a secondary backup role, supporting only telemetry and telecommand traffic for the satellites and ground stations.
4) Data and product processing – to generate mission products based on data from Metop-B, additional product processing facilities were required, as were specific processing rules handling Metop-B raw data, auxiliary data and products. These were collocated with nodes used for Metop-A product generation but configured differently as the same physical node cannot generate the same product type for different satellites. Prior to the implementation of the Metop-B specific upgrades, an earlier obsolescence upgrade of the processing system also introduced significantly higher performance for the Product Processing Facility

Figure 8. The Metop satellites are operated via two CDAs collocated in Svalbard, Norway and linked to the operational ground segment in Darmstadt via fibre-optic and satellite communications links.

nodes that was a pre-requisite for the introduction of Metop-B. As this upgrade involved the introduction of water-cooled processing systems, an update to infrastructure monitoring systems and procedures was also required to address the new risk of coolant water leak.

5) Dissemination and user services – these are typically multi-mission facilities where introducing support for additional satellites is an integral aspect of the system design and operating processes. Nevertheless, these processes had to be exercised to ensure that Metop-B data and products are archived correctly and will be disseminated to users. The office procedures employed by the user support team required update to accommodate the new set of Metop-B products and services available for user request.

2. *Standardised Approach for Recurrence Testing*

A number of preparatory activities for Metop-B, including the functional verification and operational validation of the modified systems and operations concepts, operations training and rehearsals, were captured in a set of standardised definitions that are available for re-use when it comes time to prepare for Metop-C.

Pre-launch system functional verification was performed as a collaborative undertaking between the Program Development (PRD) and Operations (OPS) Departments of EUMETSAT. Verification was conducted according to a series of 25 test cases (designated the 05-xx test cases) that exercised all aspects of the system to the maximum extent possible under the GS-3 test environment, demonstrating the system"s capabilities and performance against the specified requirements. Operational validation was then performed on the GS-2 validation environment against the satellite simulator according to a further set of 21 test cases (designated the 06-xx test cases) designed to demonstrate the ability of the combined verified system and operational procedures to perform the required mission.

This set of nearly fifty standardised test cases designed to demonstrate the system"s capabilities, performance and operability for Metop-B, will be readily applicable for use in future system tests where a general re-verification and re-validation of the system is required. This is not limited to only recurrence scenarios and can be applied to the obsolescence evolutions that are periodically required through the lifetime of an operational system.

3. *Looking ahead to Metop-C Testing*

Further re-verification and re-validation of the EPS System lies ahead as part of the preparations for the launch of Metop-C around 2017. While much of the recurrence preparatory work for Metop-B centered on the fact that the EPS System had not been completely verified or validated for dual-Metop operations, preparations for Metop-C will have to address the fact that the EPS System was not designed to concurrently support three spacecraft in orbit.

Assuming both Metop-A and Metop-B remain operational and under control at the time of Metop-C launch, changes to this design will be necessary in order to support the third Metop satellite. The level of effort required to redesign, re-verify and re-validate the EPS System for Metop-C will likely therefore be greater than was necessary for Metop-B preparations. This will remain true even if the high-level planning for EPS/Metop operations foresees de-orbiting Metop-A after a successful launch and commissioning of Metop-C.

The verification and validation test cases defined for Metop-B will be used as the basis for the Metop-C test effort. Although some aspects of these test cases may require update, they will demonstrate functions and capabilities that are required for Metop-C, and will exercise operational scenarios equally as valid for Metop-C as they are for Metop-A and Metop-B.

Later in this paper, the option to bring forward Metop-C related system upgrades and initial verification activities is discussed. This would be to take advantage of the current high level of operations team expertise in such activities as a result of the Metop-B preparations.

D. Systems Operations and Recurrence

Modifying the operational concept to account for recurrence requires consideration of a number of factors, over and above the spacecraft operations, system design and operational maintenance issues described previously.

1. *Operations in a Single Environment*

The use of the three ground segment environments described above is intended to keep separate the preparations for recurrence from the system that is currently performing actual operations. However, this is not always possible, and must eventually be given up in any case as the addition of modifications to support the new satellite has to be implemented on the operational ground segment in order for recurrence to be completed.

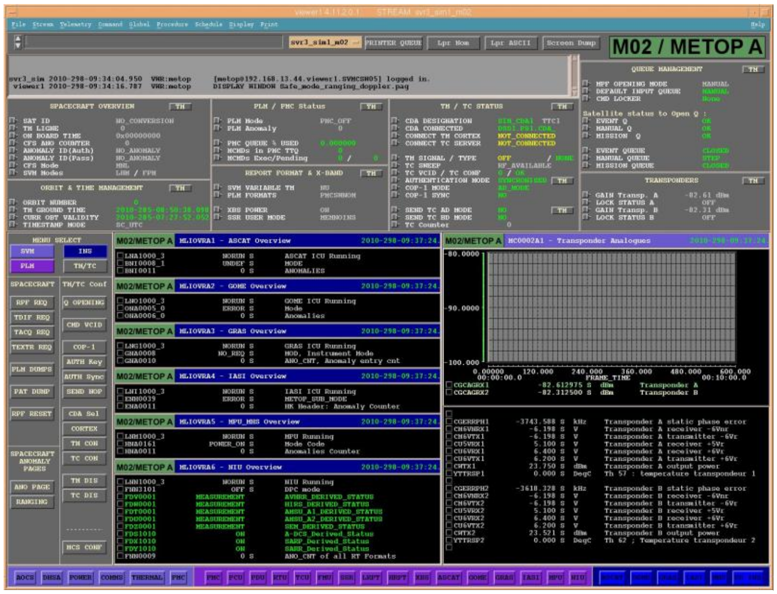

Figure 9. Spacecraft Controller Viewer showing Spacecraft ID

To safely and effectively manage different satellites on a single ground segment, the definition of each individual satellite must be fully understood so that the impact of any change on the system can be properly assessed. This can range from the physical allocation of work positions to different satellites to the deployed multi-satellite facility configurations and the use of indicators to clearly identify the spacecraft being supported from a given location.

In EPS, two similar but separate work positions have been created to ensure that the spacecraft operations controller (Spacon) differentiates between Metop-A and Metop-B. While the system operations controller (Syscon) will remain in a single position supporting all spacecraft, the Spacon will move between these two positions as required according to the satellite being operated. To emphasise the identity of the satellite being controlled, the displays are each automatically tagged with the spacecraft identifier. These are colour-coded per satellite and are taken directly from the stream identifier, avoiding any need for manual configuration (see Fig. 3).

2. Changes to System Maintenance Concepts

Many system maintenance activities will be unaffected by recurrence, while others may be affected to lesser or greater degrees.

Taking Metop-B as an example, a subset of the procedures to address system maintenance or contingency responses require updating to reflect changes to the availability of suitable periods for the introduction of changes.

Three specific examples are detailed below:

1) The MCS facility is designed using a stream approach, where operations of different satellites are executed on a single server (with redundancy) but separated into satellite-specific streams for command handling and telemetry processing. During system development, MCS stream crashes were frequently encountered, requiring a restart of the stream or occasionally a swap to the redundant spacecraft server. With only a single Metop in orbit, there was easily sufficient time to perform the necessary recovery before the next satellite pass. However, with a second Metop to be supported, this time is reduced by more than half, making it necessary to identify options for a faster recovery and to modify mission rules to anticipate the increased risk of losing a pass. System robustness has thankfully increased greatly since and the stream processes are now highly reliable and only very rarely subject to crashes.
2) EUMETSAT maintains two Command and Data Acquisition (CDA) ground stations collocated in Svalbard, Norway to support both Metop-A and NOAA-19 satellites. Due to orbital differences, these two satellites periodically enter conflict where a single antenna is unable to support both. This would not normally represent a problem as the CDAs are allocated to support Metop-A from the CDA-1 and NOAA-19 from CDA-2. However, when a CDA is unavailable due to planned maintenance or unforeseen contingency, EUMETSAT is unable to accept a request for support from NOAA during such periodic conflict. Introducing Metop-B will only increase the chance of conflict with NOAA-19 and result in an increased risk of lost passes during maintenance or contingency. This must be reflected in the operational interface documentation with US National Oceanic and Atmospheric Administration (NOAA).
3) Data processing and communications systems are also more constrained after the introduction of Metop-B. With current transfer rates, the full orbit of Metop-A data is transferred from Svalbard to Darmstadt in approximately 80 minutes, leaving a brief but usable window of opportunity for maintenance on the Front End Processors (FEPs) in Svalbard, the communications systems involved in the transfer, and on the Product Generation Facility (PGF) in Darmstadt. Taking into account the planned near-180° orbital offset between Metop-A and Metop-B, there will no longer be a clear maintenance window where changes can be implemented on these systems without increased risk of impact on the acquisition, transfer and reception of

mission data. Mission rules for operational prioritisation will ensure mission data from the prime operational satellite remains unaffected, but another option under consideration is to accelerate the data transfer rates in order to recreate maintenance windows, albeit smaller than at present.

3. Implementing Modifications to the Operational Environment

Implementation of changes within the operational environment must also be performed in a manner that minimises impact. The presence of an additional satellite being controlled from this environment can itself mandate changes to the way such changes are performed.

For example, GS-1 currently only controls the Metop-A satellite, allowing a period of some 80 minutes between passes for system modifications related to spacecraft monitoring and control (M&C). However, the introduction of Metop-B reduces the gap between passes available for M&C system modifications to only 30 minutes. This requires that such modifications be performed in significantly reduced time periods, or enforce a change to the operations concept such that a pass by one or other satellite is not supported. While not necessarily preferred, this approach can be mitigated through manipulation of the command queues to bring forward any commanding activities that would be otherwise impacted, and by using the GS-2 environment to monitor the telemetry during the outage of GS-1.

4. Changes to Operational Documentation and Procedures

The introduction of a recurrent satellite will impact on the operational documentation and procedures set. The impact on spacecraft operations and related documentation has already been discussed, but there is also impact on the System operations documentation and procedures that must be addressed.

Much of the procedure and documentation updates would consist of simply replacing generic references with individual references to the different satellites, or duplicating specific references for one satellite with equivalent references for the new satellite. Such upgrades would be subjected to the normal operations processes for procedure or document update, review and approval.

A smaller group of changes to operational procedures and documentation require more complex updates as they are mandated by the presence an additional satellite in orbit and represent a change to the way operations are performed, instead of merely adding references to an additional satellite. This may be due to increased utilization of system resources, reduced opportunities for the implementation of system changes or reconfigurations, or reduced time available to implement a contingency recovery before an operational service is impacted.

5. Changes to Operations Processes

Several standard operations processes must be adapted to take account the introduction of any new system element – including a recurrent satellite.

In EUMETSAT, this includes the standardised processes and related bespoke or COTS tools for anomaly processing and configuration change management, where the new element(s) must be added to the existing operational configuration. The Operations Baseline in the Documentation Management System (DMS) must also be updated to take into account new aspects of operational knowledge such as the new satellite"s Flight Operations Manual (FOM), satellite-specific procedures, and so on.

C. Managing the Operational Transition

A number of activities are required to prepare and implement a transition of operational services from one satellite to another. This activity involves a wide range of stakeholders, internal and external to EUMETSAT. The readiness of all stakeholders must be assessed and combined to give and overall readiness for the operational transition.

1. Satellite and System Verification

This process starts with the most obvious component of the system, the Metop-B satellite itself. The state of the satellite is assessed immediately after launch and throughout the Launch and Early Orbit Phase (LEOP) and Satellite In-Orbit Verification (SIOV) phase until it has reached its operational configuration. Any deviation from the expected performance and capabilities must be assessed for impact on the expected lifetime of the satellite and its ability to perform the intended mission.

Two changes to the mission of Metop-A were implemented shortly after the start of operations. The first change was the decision not to maintain the Low-Rate Picture Transmission (LRPT) operational services originally foreseen in the EPS operational services definition. This function was verified after launch but was removed from the list of EPS/Metop operational services after it was concluded that there was no user demand for such a service. The second change was triggered by the in-orbit failure of a component of the High-Rate Picture Transmission (HRPT) system due to impact of heavy-ion particles. In the subsequent investigation, it was concluded that the system design was vulnerable to a specific type of particle impact, and that operations should be restricted to avoid Polar regions and the South Atlantic Anomaly.

On the ground, the overall performance of the ground segment is continually assessed against its own performance and capability requirements to ensure the maximum quality, availability, and minimum timeliness of operational services to users. During the Commissioning Phase after the launch, the ability of the ground segment to support operations is initially assessed. Once the key functions for spacecraft operation are verified, attention moves to the generation of mission data products.

2. Product Generation and Trial Dissemination

Product operations for a new satellite begin with initial generation on the validation ground segment and an initial Product Validation Review Board (PVRB) which approves the generation and test dissemination from the operational ground segment to key stakeholders.

As an integral part of test dissemination to key stakeholders, data and products from the new satellite are made available to EUMETSAT‟s operational partners, such as NOAA and the French Centre National d‟Etudes Spatiales (CNES). They, along with the various national weather services of EUMETSAT member states, will begin the process of assessing the compatibility of their own systems with that data and preparing their own users for Metop-B derived services.

A further PVRB will approve the transition to trial dissemination which will make the new products available to a broader audience and begin preparations for the operational transition. This is the first opportunity for many users to receive and process data from the new satellite.

3. Transition Review, Approval and Planning

Once the satellite configuration has been finalized, and the dissemination of products from the new satellite has entered a routine phase, EUMETSAT will perform a high-level “constellation” review of the above components in order to determine if the new satellite is ready to assume responsibility for the provision of operational services. The review will also include the status of other EUMETSAT satellites in the same program and the proposed system configuration (satellites and services) after the transition to the new satellite. Inputs from the user community and key stakeholders all contribute to the review process, providing readiness statements for the transition. Finally, assuming there are no preventing factors, a transition date and time is formally agreed with all stakeholders. This is then implemented at an operational level.

Typically, the former prime operational satellite transitions to a backup role. In some cases, this includes provision of additional operational data to complement the new prime operational satellite, such as the Rapid-Scanning Service performed by Meteosat-8 after Meteosat-9 assumed the prime operational geostationary mission, or the intended operation of Metop-A to provide continuity of full data in parallel with the new provision of data from Metop-B.

In contingency situations, where the new satellite is not able to assume full responsibility for all operational services, a “split mission” scenario may be implemented where some operational services are maintained by one satellite and the remaining services by another. Such a configuration is dependent upon the nature of the specific anomaly encountered and the needs of the operational services, and can significantly increase complexity in the operations concept.

V. Production Operations

The science data from Metop satellites are processed automatically in Near Real Time (NRT) to high level products for dissemination and archiving. Here the recurrence of Metop-B is translated into strictly identical product format and product processing algorithms between Metop-A and Metop-B. On request from the EUMETSAT users, both sets of satellite products will be processed and disseminated in NRT, as the recurrent satellite brings the benefit of increased spatial coverage with the same level of quality. In a further stage, new, multi-satellite products will be introduced in addition to the existing suite.

When introducing an additional satellite, the following top level objectives were assigned:

- Managing of product processing resources;
- Validating the production system;
- Verifying and validating the new products;
- Monitoring the quality of products;
- Ensuring the continuity and expansion of the operational services.

A. Production Facilities Handling

The NRT production architecture at the EUMETSAT central facilities is based on a central Product Generation Facility (PGF) managing a farm of Product Processing Facilities (PPFs).

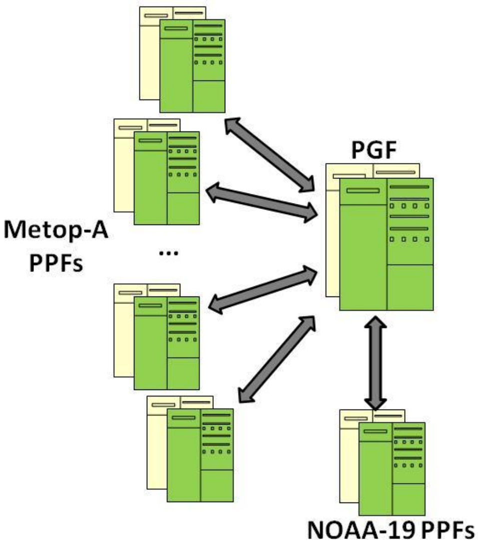

Figure 10. Processing Facilities for Metop-A and NOAA-19

In this context, the PGF has the triple role of (i) ingesting and conditioning the raw satellite and auxiliary data for processing; (ii) scheduling elementary production tasks for the PPFs to perform; and (iii) dispatching the products for dissemination.

The PPFs are dedicated to batch processing of work orders submitted by the PGF. They are implemented in virtualised servers. Redundancy is managed by making servers available to the PGF as either operational or spare. New work orders are submitted to one of the available operational PPFs and if they all fail then one of the spare servers is activated automatically.

New resources for processing Metop-B products in parallel with Metop-A equivalents were allocated in the processing system. Because of its essential role in controlling and monitoring the production, the PGF remains a single facility, and is provided with additional memory, storage and processing power, in order to cope with three satellites in parallel. On the other hand, the PPF farm is expanded with new servers, with each server specialised in one set of products from one satellite. The satellite specific aspects of PPF configuration are managed by the PGF – typically in the form of auxiliary data for processing, with calibration tables, etc., and the PPF servers are configured in a uniform manner. This is shown schematically in figures 9 and 10.

B. Production System Verification

The production system has been verified early on for multiple satellite operation by simulating Metop-B science data input and production schedule. Metop-A raw satellite data provide highly representative test data for Metop-B for most of the data circulation and production testing purposes and have been used in most of the system tests.

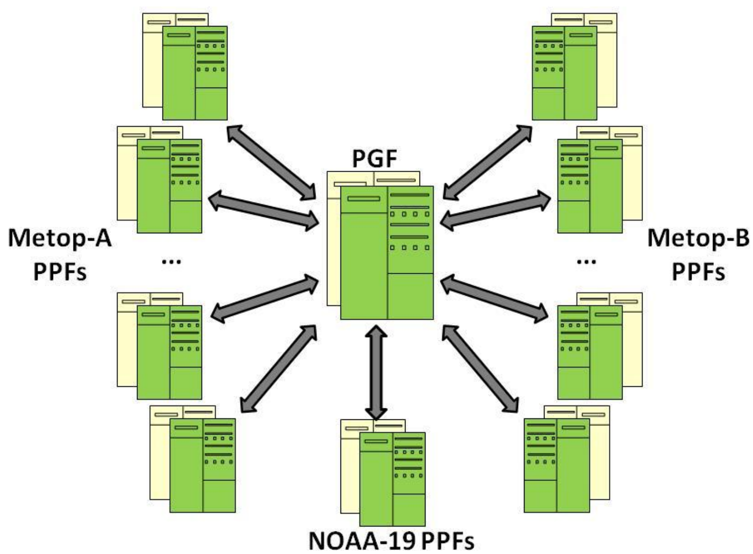

Figure 11. Updated Processing Facilities for Metop-A, Metop-B and NOAA-19

In an initial test configuration, the simulated orbit and schedule for Metop-B are the same as for Metop-A; the live Metop-A raw data are copied in real-time to a simulated stream of Metop-B raw data. This was highly successful in verifying data flows and capacities; however it was lacking realism in the scheduling and implementation of operations and in the occurrence of data bursts. The test configuration applied in most of the system end-to-end and non-regression testing has therefore used a limited set of Metop-B orbits sourced from recorded Metop-A raw data, and a realistic simulation of the schedule and orbit of Metop-B. The raw recorded data are then fed repeatedly by a FEP into the validation ground segment; the calibration of the on-board time stamps is adapted so that the test data look like live Metop-B data. This provides for realistic peak loads, products and data flows. Long duration tests have extended over weeks in order to establish confidence in the stability of the system performance.

In separate tests, PPFs have been processing actual data from Metop-B satellite testing, e.g. in thermal vacuum tests, in order to verify the specific processing configuration such as calibration tables.

C. Bringing Products into Operations through Phases

The Cal/Val approach planned for the new satellite is basically the same followed with the Metop-A satellite. Taking advantage of a stable, operational production and dissemination system, it is planned to disseminate early products to a small set of users who contribute to the validation of the Metop-B products.

Product validation follows a three-step process, applied in satellite commissioning as well as normal operations for product evolutions. Following initial sanity checks, verification of the radiometric calibration and geo-location of the products, dissemination of the products for demonstration may begin. It will be restricted to users who have already committed to monitor and evaluate those products. In a second phase, full calibration of the products is pursued, e.g. calibration of ASCAT sigma-0 products with ground-based transponders. Validation testing will include comparison with forecast fields, ground-based observations including radio-sondes, other satellite observations, etc. When the quality of products is estimated sufficient, their status will change to pre-operational and unrestricted dissemination will start. Following further validation to ensure that the products are fully compliant with their specifications, the status of products will become operational.

Each of those phases is concluded by a production validation review board that scrutinises the available validation results and the status of all facilities contributing to the product service, and gives the go-ahead for the transition to the next phase. The review board is composed of EUMETSAT scientists and engineers and may include partners as well as user representatives. Product validation reports are input to the Commissioning Hand-over Review and eventually published on the EUMETSAT Web site.

Product Cal/Val operations make full use of the validation ground segment prior to starting dissemination. All validated product processing is transferred to the operational ground segment for dissemination.

D. Production Operations with Multiple Spacecraft

Validating the products of a new recurrent satellite in the presence of a fully operational one brings some advantages and constraints.

In its current, fully operational and well characterised status, Metop-A provides a permanent reference for all the EPS products. It is of course envisaged to use that reference for comparison with the new Metop-B products. However, the observations from the two satellites are never well co-located in space and time because of the 49-minute spacing between them, and the maximal separation of their ground tracks it causes. Therefore, such comparisons viewing the Earth and atmosphere will be mostly meaningful in global statistics, and also by double difference to a common reference. The ground-based ASCAT transponders also provide a very stable and well characterised reference target for directly comparable measurements by the two instruments.

During Cal/Val, the product processing algorithms are frozen; the only evolutions envisaged are those related to tuning of the Metop-B performance. This is imposed by the need to keep Metop-A products a stable reference, and the limited size of the operation and validation teams. Thus, important evolutions of the EPS products have been postponed until the end of the commissioning, for instance the noise monitoring in the ATOVS-AVHRR products or the upgrade of the ASCAT full resolution product. In the future, product upgrades will be simultaneously introduced on both satellites, following the same three-step process as explained above for product cal/val.

E. Use of Off-line Environments

The elaboration of quality indicators associated to the Metop products is performed both on-line and off-line. On-line quality control and flagging are important for the products used in near-real time as well as for those retrieved from the archive. However they are limited by the restrictions, in NRT processing, on the availability of stable external references, and of long term instrument performance history. Such restrictions can be relaxed when performing additional quality control off-line in dedicated environments.

A Calibration and Validation (Cal/Val) Facility was developed as part of the initial system configuration for EPS, with a strong focus on data access, visualisation and analysis, comparison with observation and model data, and a capability to perform automated analysis and reporting.

As a complement, the EPS programme has been the initial target for a powerful, scalable off-line environment. Subject to lighter operational constraints than the NRT production, that environment automatically extracts a large range of instrument and performance parameters for accumulation in long term time series, stored in a data warehouse. The comparison of product parameters with stable independent references, such as NWP forecast fields or meteorological observations, provides additional time series. Starting from those long term series, off-line sophisticated tests such as trend analysis, correlation with spacecraft events, etc., are performed and reported on demand as well as automatically. The resulting reports are published on the EUMETSAT Web site and kept for reference.

F. Operational Services

Ensuring the continuity of the operational services providing products from Metop-A and NOAA-19 with a high guaranteed level of availability, timeliness and quality, while introducing a new Metop satellite in the EPS, was one the top level objectives of EUMETSAT and the previous paragraphs demonstrate how this is achieved by all the contributing elements of those services. On the other hand, EUMETSAT stakeholders and users have very early indicated how valuable would be an expansion of those services with additional products from the recurrent satellite, in particular enhancing the spatial coverage of observations thanks to the phase opposition of Metop-B against Metop-A. As indicated above, all products from the prime and secondary satellite will be derived and disseminated in parallel. The corresponding increase of dissemination bandwidth has been secured. Metop-B based services will be monitored and supported in the same manner as the current ones, the notion of prime satellite applying throughout the service provision chain. The dual satellite services will be reviewed every year as part of the extension of Metop-A mission.

Operating two identical sets of instrument also provides an opportunity for an improvement in some services. Atmospheric Motion Vector (AMV) products are currently derived above the polar caps from successive AVHRR views of the same areas. With a single satellite, such views are typically separated by the orbit period yielding low resolution. Combining AVHRR scenes from both satellites will virtually double the frequency of observations, hence the resolution of AMVs. The observation of rapidly evolving phenomena, typical of the early morning hours, by high resolution spectrometers such as IASI is also expected to reap benefits from the successive satellite passes. Concerning GOME, users have requested taking advantage of the high flexibility of the instrument sampling: where the swaths of the two satellites quasi fully overlap, the two GOME instruments could be configured to observe each one half of that overlap region. Halving the swath allows doubling the spatial resolution in those regions.

VI. Team Issues and Operational Knowledge

A. Evolution and Maintaining Expertise

The long lifetimes for typical EUMETSAT programs, combined with the normal turnover of engineering and controller personnel, can present a problem when maintaining the necessary operational expertise in the operations team. Several factors can impact on this, including the normal turnover of personnel in an international organisation, contractor fixed terms contracts and the need to periodically resubmit roles to the tender process, the redeployment of team members within the organisation to other development or operational programs, and the general reduction of team size as a program matures through increased automation and increased team competence and experience.

In the example of EPS/Metop, the recurrent transition to Metop-B will take place while the operations team retains a relatively high percentage of personnel involved in the original development and validation activities leading up to the launch of Metop-A in 2006. However, the Metop-B launch will take place approximately one-third of the way through the complete lifetime of the EPS/Metop program, which is expected to last until at least 2022. The remaining ten or more years of the EPS/Metop program, including the transition to Metop-C around 2017, will have to rely on the remaining team members that have original experience of Metop-A and/or Metop-B, and the repository of operational knowledge available to the newer team members.

Key here is the need to capture and maintain operational knowledge in an effective manner that is easily accessible to the Operations Team. This is discussed in detail in a separate paper[1].

Additionally, preparing new team members can take several months from initial training until optimum operational effectiveness, making it unattractive to invest in such preparations unless a new team member is genuinely needed for the long term. Short term boosts to the team – such as might seem useful during recurrence or other periods of high-loading – are actually of little benefit.

There is also a good case to be made for making use of expertise while it is available. For this reason, a review will shortly begin in EUMETSAT to determine the most effective approach to be adopted for preparations toward Metop-C. Formal validation, training and rehearsals must naturally be performed close to the launch of Metop-C. However, with a current Operations Team that is fully experienced with the Metop-B preparatory activities, there is an option to perform the necessary system upgrades and initial system verification for Metop-C immediately after the completion of Metop-B commissioning. This early start to preparations would reduce the burden on the Operations Team at the time of Metop-C, potentially avoiding increased cost and greater risk later.

B. Training and Rehearsals

A nine-month period of operations team preparation for Metop-B began with dedicated team training activities and culminated in the execution of a set of operational rehearsals designed to both complete their familiarization and assess the effectiveness of the training and operations concept validation.

1. Team Training

All training information required to prepare new team members for involvement in a EUMETSAT operational program is defined in the Operations Training Plan. When a major change to an existing program is under development, a Preparatory Training Plan document is prepared that defines the training required to bring existing operations team members into readiness for the new configuration. The content of the preparatory training plan is then incorporated in the new baseline training regime defined an updated operations training plan after the new configuration has become operational.

Following this approach, a dedicated preparatory training plan was developed to define the additional training required for members of the Operations Team in preparation for both Metop-B and a concurrent major system modification to introduce an Antarctic Data Acquisition capability. After the successful launch and in-orbit verification of Metop-B, the content of this preparatory training plan will be added to the operations training plan.

Figure 12. The EPS Operations Team underwent a comprehensive training program and completed a series of operationally-representative rehearsals in preparation for the launch of Metop-B.

In the longer term, an equivalent Metop-C Preparatory Training Plan will be defined to identify training specific to the introduction of Metop-C and, assuming no in-orbit failures for Metop-A or Metop-B, operations of a three-satellite constellation.

2. Operations Rehearsals

With any change to the operations concept, validation of the upgraded operational system and training of the Operations team should be followed by a comprehensive set of operationally-representative rehearsals. These have a dual purpose of completing the familiarization of the operations team with the revised operations concept and updated procedure set while acting as a final validation of the system and operations procedures.

The Metop-B operations rehearsals campaign spanned a three-month period where six formal rehearsal activities were performed. Each of these addressed one or more rehearsal scenarios including operations during LEOP and SIOV, data encryption operations, satellite manoeuvres, on-board software management and contingency operations. Incorporated into each rehearsal was a specific set of fundamental controller activities relating to the execution of on-console operations, such as handling workstation and stream crashes, routine passes via external ground stations, user information management, and contingency commanding scenarios.

As the rehearsal scenarios presented are likely to remain valid for the duration of the EPS/Metop program, the operational rehearsals campaign for Metop-B will be used as the baseline for the equivalent Metop-C activity, modified to take into account specific differences between two- and three-satellite constellation operations.

VII. Conclusion

Expertise in the handling of recurrent spacecraft within the context of an existing operational program has been clearly established as a key capability for the type of long-duration programs that are at the core of EUMETSAT activities. This has been incorporated into EUMETSAT program management and operations concepts at a fundamental level to ensure that recurrence is properly considered at all levels of operations and within each phase of a program.

Recurrence within EUMETSAT geostationary satellite programs in recent years has demonstrated the effectiveness of this approach. This will be further exercised following the forthcoming launches of recurrent satellites for both the Meteosat Second Generation and EUMETSAT Polar System programs in the second half of 2012, leading to operational transitions in 2013. Further recurrence is planned in each of these programs, and in other programs supported by EUMETSAT, over the remainder of this decade before the introduction of successor programs to support EUMETSAT‟s geostationary and polar-orbiting missions.

Appendix A
Acronym List

AMV	Atmospheric Motion Vector
AOCS	Attitude and Orbit Control System
ASCAT	Advance Scatterometer
ATOVS	Advanced TIROS Operational Vertical Sounder
AVHRR	Advanced Very-High Resolution Radiometer
CDA	Command and Data Acquisition
CHART	Component Health Assessment and Reporting Tool
CNES	Centre National d'Etudes Spatiales (of France)
COTS	Commercial Off The Shelf
CV	Command Verification
DMS	Documentation Management System
EPS	EUMETSAT Polar System
EEPROM	Electrically-Erasable Programmable Read-Only Memory
EPS-SG	EUMETSAT Polar System – Second Generation
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCP	Flight Control Procedure
FEP	Front End Processor
FOM	Flight Operations Manual
GEMS	Generic Event Monitoring System
GEANT	Gigabit European Advanced Network Technology
GFT	Generic File Transfer
GMT	Greenwich Mean Time
GOME	Global Ozone Monitoring Experiment
GS	Ground Segment
GUI	Graphical User Interface
HRPT	High-Rate Picture Transmission
HTML	Hyper-Text Mark-up Language
IASI	Infrared Atmospheric Sounding Interferometer
IV&V	Integration, Verification and Validation
LEOP	Launch and Early Orbit Phase
LRPT	Low-Rate Picture Transmission
M&C	Monitoring and Control
MCS	Monitoring and Control System
MCF	Mission Control Facility
MFG	Meteosat First Generation (geostationary satellite system)
MPF	Mission Planning Facility
MSG	Meteosat Second Generation (geostationary satellite system)
MTG	Meteosat Third Generation (geostationary satellite system)
NOAA	National Oceanic and Atmospheric Administration (of the USA)
NRT	Near-Real Time
NWP	Numerical Weather Prediction
OPS	Operations Department (of EUMETSAT)
OSTM	Ocean Surface Topography Mission
PGF	Product Generation Facility
PI	Procedure Initiator
PPF	Product Processing Facility
PRD	Program Development Department (of EUMETSAT)
PVRB	Product Validation Review Board
SIOV	Satellite In-Orbit Verification
SQL	Structured Query Language

SVT	Satellite Verification Testing
STOL	Spacecraft Test and Operations Language
TM/TC	Telemetry and Telecommand

Appendix B
Glossary

ARGUS	EUMETSAT internal offline analysis and technical computing environment
EPOCH	Telemetry and telecommand COTS software product, from Integral Systems Inc.
EUMETCast	EUMETSAT dissemination system utilising direct video broadcast satellites
Metop	Meteorological Operational (satellite of the EUMETSAT Polar System)
MATLAB	Numerical computing environment and programming language, from MathWorks
Spacon	Spacecraft Operations Controller
Syscon	System Operations Controller

Acknowledgments

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