EUMETSAT Multi-Mission Administrative Message goes Operational

A. Damiano[1]
Rhea Systems S.A., Darmstadt 64295, Germany

P. L. Righetti[2], A. M. Soerensen[3]
EUMETSAT, Darmstadt 64295, Germany

Since 2006 EUMETSAT has operated an early type of administrative message for the Metop-A mission. In 2008 the possibility to improve the administrative message and to extend the improvements to the follow-on missions was investigated (named Multi-Mission Administrative Message - MMAM - and described in the paper "An XML-based Administrative Message for LEO Earth Observation Satellites" presented at SpaceOps2008)[1]. This paper describes the new MMAM system functions, architecture and validation activities inside a complex, fully operational system. The MMAM system has been successfully validated at several operational levels and will be first used for the Metop-B mission, whose launch is foreseen in mid-July 2012.

Nomenclature

ANX	=	Ascending Node Crossing
AOS	=	Acquisition of Signal
BOP	=	Back-up OPerational UMS
CDA	=	Command and Data Acquisition
EARS	=	EUMETSAT Advanced Retransmission Service
EPS	=	EUMETSAT Polar Sytem
FDF	=	Flight Dynamics Facility
HRPT	=	High Rate Picture Transmission
IF	=	Interface
LEO	=	Low-Earth Orbit
LRPT	=	Low Rate Picture Transmission
MCSS	=	Monitor and Control Satellite Server
Metop	=	Meteorological Operational satellite (EPS space segment)
MMAM	=	Multi-Mission Administrative Message.
MPF	=	Mission Planning Facility
NOAA	=	National Oceanic and Atmospheric Administration
OBT	=	On-Board Time counter (the on-board "clock")
TLE	=	Two-Line Element orbit vector
UMS	=	User Message System
XML	=	eXtended Mark-up Language

[1] Flight Dynamics Operations Engineer, Control Centre Division, EUMETSAT-Allee 1, 64295 Darmstadt,
[2] Flight Dynamics Operations Engineer, Control Centre Division, EUMETSAT-Allee 1, 64295 Darmstadt
[3] Flight Dynamics Team Manager, Control Centre Division, EUMETSAT-Allee 1, 64295 Darmstadt

I. Introduction

Administrative messages are used to keep satellite system users aware of the satellite/data processing status and of events relevant to the system operations (like instrument calibration or satellite maneuvers). The original message used by the LEO Metop mission is valid for a rolling window of 36 hours (22 orbits) and is uplinked every 12 hours by the EUMETSAT CDA in Svalbard, Spitsbergen Island to the satellite, which then re-transmits it to the Local Users, primarily the EARS stations network, via its HRPT antenna. The message itself is also available in a dedicated EUMETSAT web page accessible to registered Users.
The message is a binary file, whereas some of its areas are plain ASCII sections, as for instance the 5200 bytes-long free-text buffer. The current administrative message is 8032-bytes long.
While the message provides the receiving Users with some basic information about satellite platform, payload status and orbital state vectors in SPOT and TBUS format, several important drawbacks have been identified:

1) Message history cannot be reconstructed: only the current message is kept.
2) Specialized software libraries are needed to propagate the state vector and geolocate the instrument products. Often those libraries only run on dedicated computer platforms. This fact contributes to raise software operational costs in forms of customized application software development, license and maintenance fees.
3) There is clear room for improvement in the geolocation precision currently attainable using SPOT and TBUS vectors. Geolocation can be affected by up to 550 m of error (SPOT) or up to 1000 m (TBUS) w.r.t the high-precision operational orbit. As a comparison, one AVHRR pixel is about 1000 m at nadir.
4) Orbital information permitting proper satellite acquisition in case of maneuvers is missing; public available TLE (from Space-Track), whose performances suffer severe degradation after large maneuvers, are normally used by the Local Users.
5) Message size is not optimized. The amount of information made available to the Local Users (mostly on free text format) is therefore quite limited.
6) Message content not standardized, as free text information is not taken from templates. The new Multi-Mission Administrative Message is an XML-formatted plain ASCII file with the following basic structure:

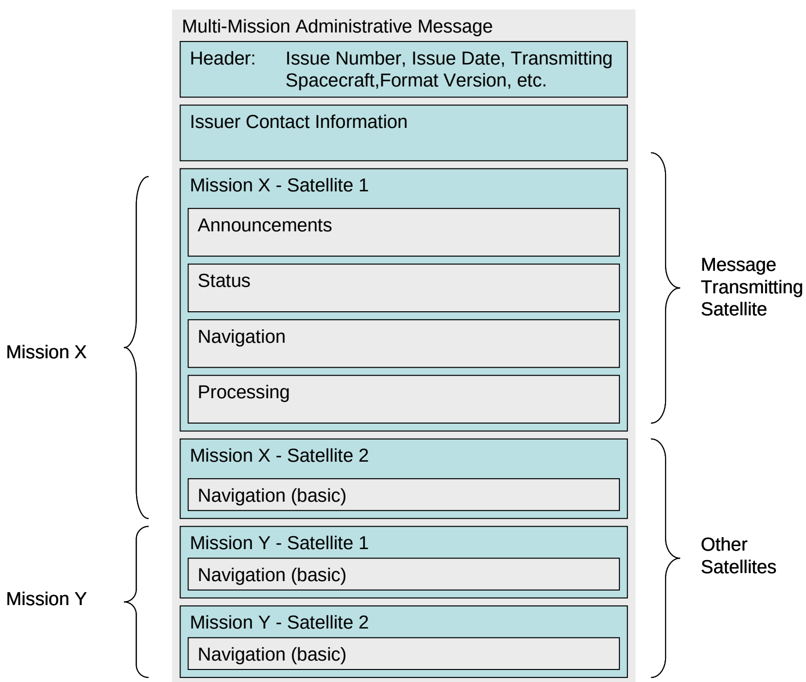


Figure 1 MMAM Message Structure

This solution offers a more structured layout as well as significant improvements to the accuracy and completeness of the navigation data.
A detailed description of the elements included in the structure can be found in the Multi-Mission Administrative Message User Guide (see reference 2).

II. Advantages of the new MMAM

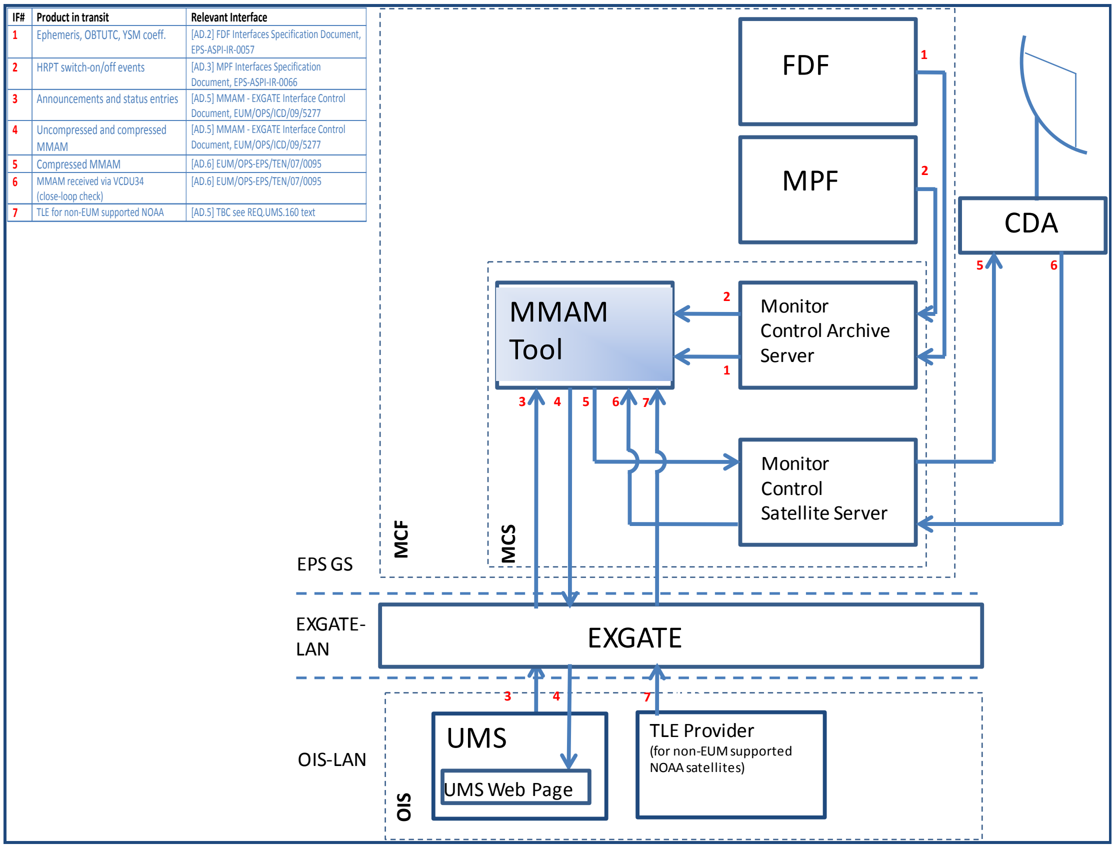
The advantages of the new MMAM are:

- improving significantly the calculation of the spacecraft position and simplifying the computation of the spacecraft orbit (no need of using specific libraries but just standard mathematical routines):
    - from 550 m (SPOT model) to 15m outside maneuver periods;
    - even larger improvements during period of maneuvers by introducing pre- and post-maneuver orbit data;
- including the information required to calculate the Metop attitude for the purpose of product geolocation and processing:
    - YAW steering mode coefficient, platform attitude biases, instrument mounting biases;
- including the information related with important events for data processing:
    - HRPT transmitter on-off times and day/night events (previously available in the free text section of the message);
- including the information needed to properly acquire the satellite accurately even in case of large maneuver execution:
    - similar information is provided for additional spacecrafts, in particular the NOAA POES/NPP and the other flying Metop satellites;
- permitting the Control Centre to issue new messages as frequently as required by operations:
    - no more bounded by a 12 hours cycle;
- permitting the Local Users to maintain the entire history of announcement issued by the Control Center:
    - individual announcements with the Administrative Message will be maintained until all Local Users stations have had several opportunities to receive them;
- formatted as an structured XML document :
    - additional information (key/value pairs) can be added without loss of backward compatibility;
    - in case of changes that are not backward compatible, old and new versions can co-exist for a period of time;
    - standardization of content of the message by use of templates;
    - easy validation, distribution, and publication of the messages using a unified XML scheme;
    - excellent performances in terms of compression, permitting to transmit a much larger amount of information.

III. Functions

Generation and operation of such a message required the development of two new facilities:

- a User Message System (UMS) tool inside the Operations Internet Server (OIS) environment, which provides and stores the satellite/ground segment announcements and status.
  The UMS is the central repository of information about the satellite platform, satellite instruments, ground segment, data processing and data dissemination to users. It provides a unified, secure portal for the experts to input and co-ordinate the data.
  UMS ensures that all announcements are numbered, that the number is increasing and that there is no gap between announcements. This allows each and any announcement to be univocally identified and referenced to within the MMAM message.
  It also provides features to archive and display past MMAM messages through a web page accessible by external and internal users.
- a MMAM tool inside the ground segment to generate, transmit and validate the message itself, as shown in the following figure:



IF#	Product in transit	Relevant Interface
1	Ephemeris, OBTUTC, YSM coeff.	[AD.2] FDF Interfaces Specification Document, EPS-ASPI-IR-0057
2	HRPT switch-on/off events	[AD.3] MPF Interfaces Specification Document, EPS-ASPI-IR-0066
3	Announcements and status entries	[AD.5] MMAM - EXGATE Interface Control Document, EUM/OPS/ICD/09/5277
4	Uncompressed and compressed MMAM	[AD.5] MMAM - EXGATE Interface Control Document, EUM/OPS/ICD/09/5277
5	Compressed MMAM	[AD.6] EUM/OPS-EPS/TEN/07/0095
6	MMAM received via VCDU34 (close-loop check)	[AD.6] EUM/OPS-EPS/TEN/07/0095
7	TLE for non-EUM supported NOAA	[AD.5] TBC see REQ.UMS.160 text

Figure 2 MMAM Functional Elements and Data Flow

IV. MMAM Operations

The functional components of the MMAM tool perform the following actions:

1. Operator interface: allow the user (analyst or controller) to access the input data, output data and event logs and to trigger the generation of the MMAM.

2. UMS data ingestion: pull and validate UMS-provided announcements and status reports (IF#3).

3. Navigation data ingestion: read orbital ephemeris, ANX times, day-night events, yaw-steering coefficients, OBTUTC correlation, TLE vector, from the MCSS server (generated by FDF - IF#1).

4. HRPT data ingestion: read HRPT instrument switch-on/off times from the MCAS server (generated by MPF - IF#2).

5. TLE ingestion: for additional spacecrafts supported by the message (from Space-Track IF#7).

6. Instrument attitude data ingestion: read instrument bias values from a configuration file inside the MMAM tool.

7. MMAM generation: build-up the MMAM message and compress it.

8. MMAM distribution: transmit compressed MMAM message to the satellite (IF#5) and uncompressed message to UMS for display to a web page accessible from internal/external users and for archive purposes (IF#4).

9. MMAM end to end validation: perform a closed-loop comparison between the MMAM message as sent to the satellite and MMAM message as read from the downlink TM stream (IF#6). Note that in order to close this loop times in the order of magnitude of 4-5 hours are needed.

In view of the upcoming launch of Metop-B, EUMETSAT decided to start using the MMAM immediately for that satellite. As soon as Metop-B is declared prime satellite (after its commission phase) the MMAM will replace the old administrative message also for Metop-A.

V. MMAM Validation

A bottom-to-top validation of the system was selected. UMS and MMAM tool single functions were first tested. Specifically for the MMAM tool two test phases were used. During phase 0 only the MMAM tool functions were tested, which are needed to perform navigation data retrieval, XML formatting, MMAM compression and MMAM distribution.
During phase 1 the MMAM tool was tested with all interfaces and all functionalities in place, including ingestion, verification and inclusion in the MMAM of announcements and status reports provided by UMS.
That solution permitted to align the development schedule of the MMAM to the one of UMS (which could be ready only for the phase 1), providing at the same time early test navigation data to the SW developer in charge of upgrading the Local Users stations.

The MMAM system has been successfully validated on several levels:

A. Stand-alone validation with UMS simulated announcements and with Metop-B simulator

This step was done in May 2011. In this phase the MMAM tool read files generated by UMS and manually transferred to the ground segment. The MMAM was generated and sent to the satellite simulator. The simulator loaded the MMAM and re-transmitted it in the X-band stream to the ground segment, where the MMAM tool validated it. This test permitted to validate against the simulator that the MMAM implementation was compliant with the space-to-ground specifications, without any risk for the for the HRPT instrument operations; this step was a mandatory pre-requisite before performing any close-loop validation with an operational satellite.

B. Close-loop validation with operational Metop-A satellite

This was a fundamental validation step, performed in June 2011, to prove the operability of the MMAM using operational assets, ground segment and the Metop satellite, even if only for a limited time-span.
For the closed loop validation with the actual satellite a timeline was carefully set-up including activities of ground segment, satellite, data processing and EARS system (see reference 3). The EARS system stations expected the old administrative message and their operation at that time was incompatible with the new MMAM. Flight Dynamics identified the time of the day when the spacecraft downlinking the MMAM would be out of visibility of the selected EARS stations. The test lasted from 12:45 and 15:41UTC, including MMAM uplink and X-band TM reception at the central site. MMAM was received in the X-band stream within 40 minutes from activation via the nominal X-band stream collected at the McMurdo (South Pole) NASA station, which is part of the EPS CDA system. The old Administrative Message was re-instated on-board afterwards, so that no EARS operational disruption was caused, exactly as planned. The timeline is given here-below:

Start Date	End Date	
2011/05/26 00:00:00.000		
2011/06/13 21:05:14.062	2011/06/13 21:19:46.578	CDA AdminMsg uplink#1
2011/06/13 22:47:47.489	2011/06/13 23:01:01.867	CDA AdminMsg uplink#2
2011/06/14 01:00:00.000	2011/06/14 12:50:00.000	AdminMsg activated
2011/06/14 09:00:00.000	2011/06/14 09:10:00.000	MMAM generated on-ground
2011/06/14 10:41:39.907	2011/06/14 10:57:09.373	CDA MMAM uplink#1 with activation at 12:45
2011/06/14 12:21:58.000	2011/06/14 12:37:24.262	CDA MMAM uplink#2 with activation at 12:45
2011/06/14 12:31:00.769	2011/06/14 12:41:55.979	LAN pass (last valid EARS pass)
2011/06/14 12:45:00.000	2011/06/14 15:41:56.326	MMAM on-board buffer activated
2011/06/14 12:50:00.000	2011/06/14 13:30:00.000	AdminMsg generated on-ground
2011/06/14 14:02:00.625	2011/06/14 14:17:21.339	CDA AdminMsg uplink#1 with activation at 16:45
2011/06/14 15:41:56.326	2011/06/14 15:57:19.999	CDA AdminMsg uplink#2 with activation at 16:45
2011/06/14 16:45:00.000	2011/06/14 23:59:00.000	AdminMsg on-board buffer activated (nominal)
2011/06/14 16:54:44.732	2011/06/14 17:08:23.677	REU pass (first valid EARS pass)

Table 1 Timeline for MMAM uplink to actual Metop-A

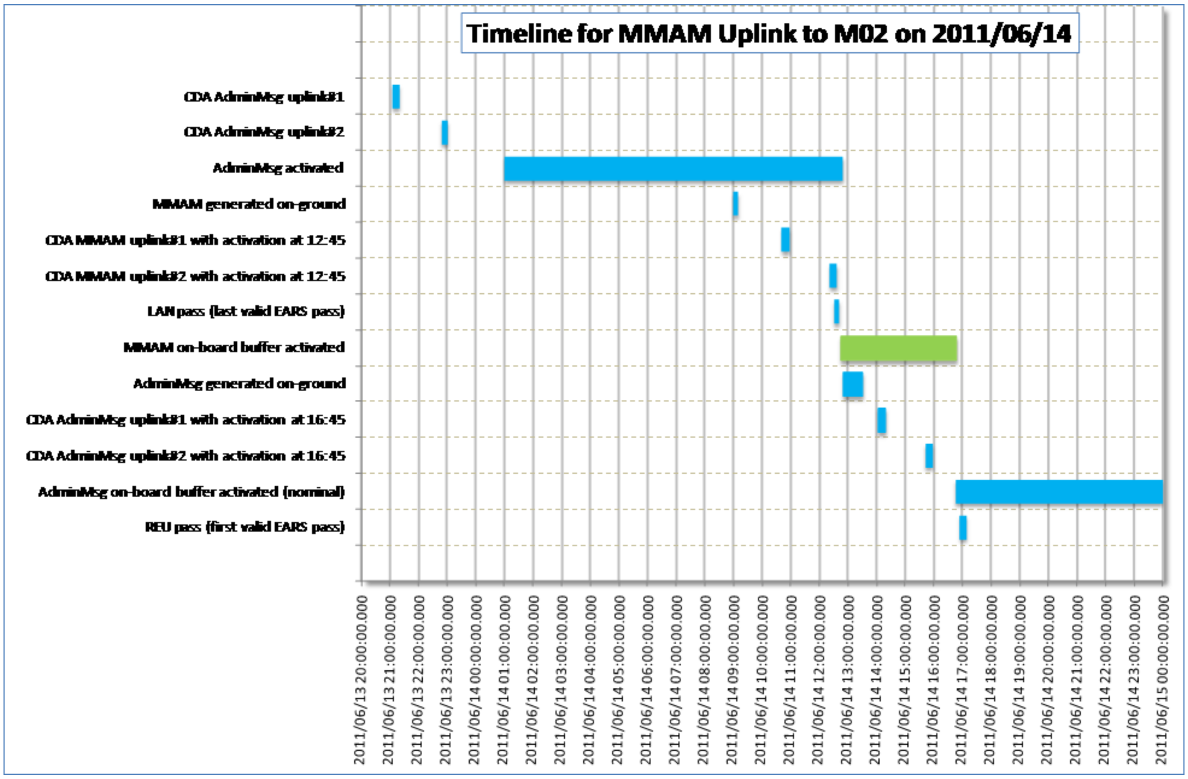


Table 2 GANTT Chart for MMAM Uplink to actual Metop-A

A 2D visualization of the Metop-A non-visibility by the EARS stations during this operational test is given here:

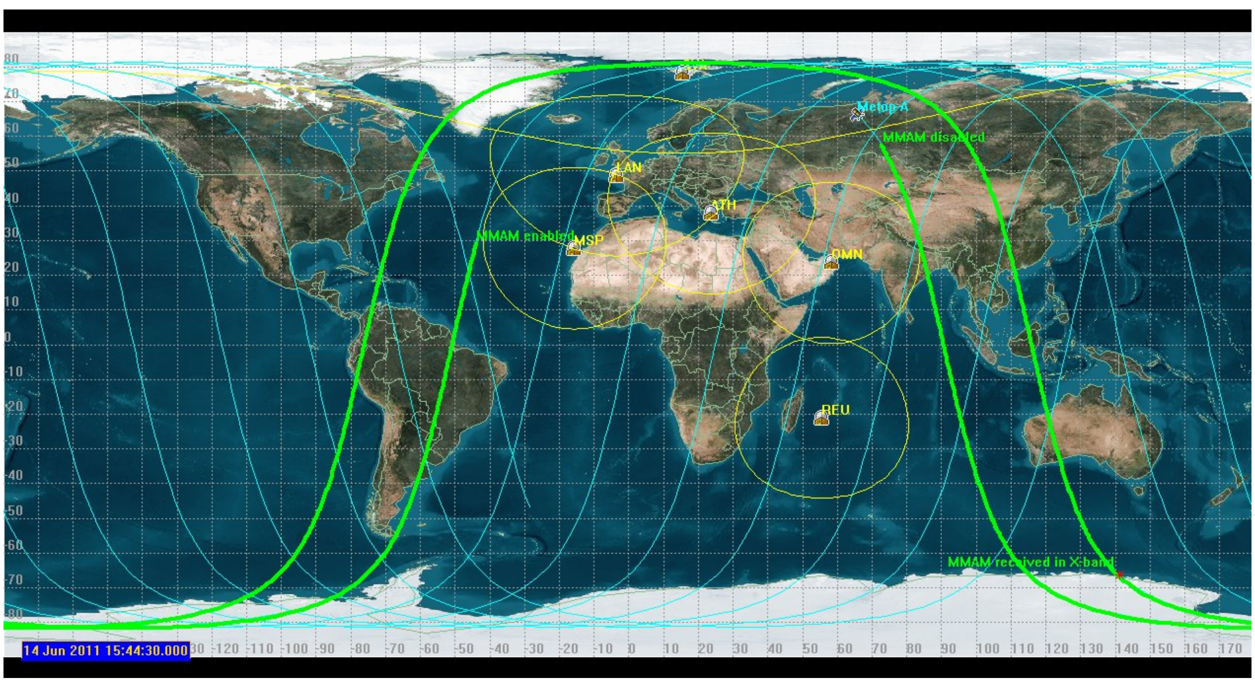


Figure 3 World map showing the Metop-A ground track while downlinking MMAM (green line)

C. **Closed-loop validation with Metop-B at the spacecraft manufacturer's facility**

Closed-loop validation activities were successfully performed in October 2011on the actual spacecraft connected to the EUMETSAT ground system during the Satellite System Validation Tests (SSVT)

D. **End-to-end with UMS simulated announcements and Metop-A and Metop-B simulators**

Operations were conducted using the nominal interfaces with UMS and two satellite simulators in October 2011. This step is needed to prove that the UMS and MMAM tool can handle multiple satellite instances.

E. **Operational validation from back-up control centers**

In November 2011 the MMAM tool was connected to the UMS version used during backup operations (Backup OPerational UMS or BOP) in order to simulate the continuity of operations even after a major accident at the main control centre. The BOP is physically located some 30km from the central site and the backup MMAM tool sits at the backup control centre (BUCC) in Spain.

A routine re-activation of the backup control centre was selected for this test. The MMAM tool in the BUCC was fed with announcements generated by the BOP and by flight dynamics data generated in the BUCC. To ensure continuity with the latest issued MMAM from the central site the operational context of the MMAM tool, of the FDF and of the UMS is automatically transferred to the respective backup functions whenever a change is implemented. The generated MMAM was sent to the spacecraft simulator connected to the backup control centre. The X-band stream from the simulator contained the MMAM which was picked up by the MMAM tool, which finally issued a successful validation flag. Manual transfer of the resulting contexts was initiated afterwards to resume MMAM operations in the central site.

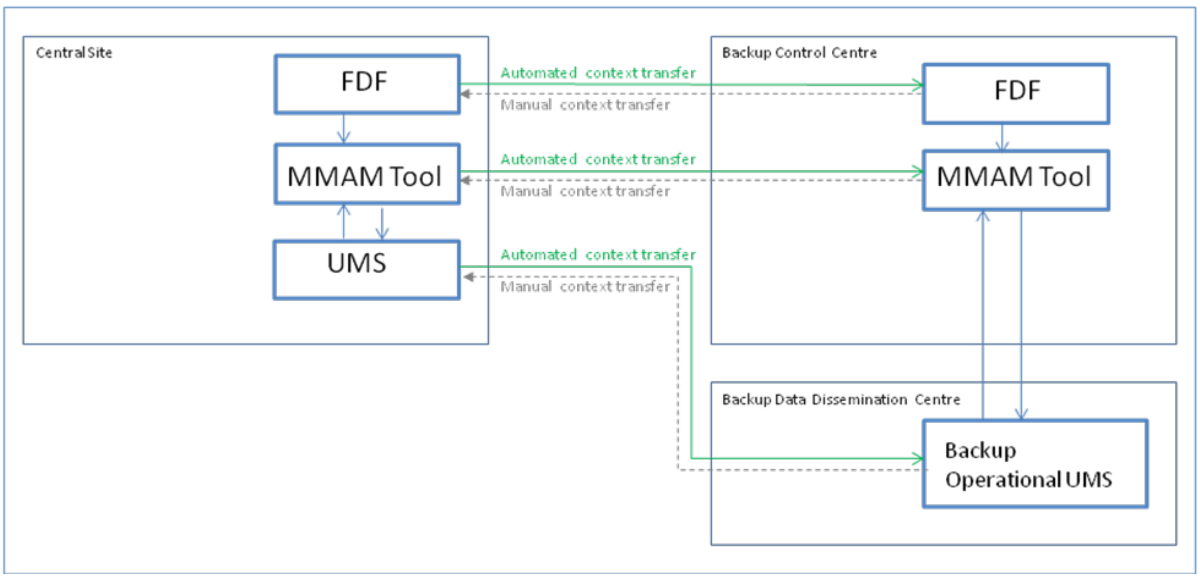


Figure 4 Automatic context transfer between central site and backup centres

F. **Trial routine generation of Metop-A MMAM**

Since September 2011 routine generation of MMAM is performed for the operational Metop-A satellite and the stored MMAM messages are accessible by users via web using the URL: http://oiswww.eumetsat.int/UMS/webapps/metopa/mmams/generated/show/all.

This MMAM generation is daily conducted by analysts and spacecraft controllers, thus effectively shadowing the operations of the old administrative message.

Message characteristics like appearance and disappearance of announcements within the message validity span are thus tested on a daily basis, to gain experience for the live operations. Furthermore continuous test data are provided for the validation of the SW developed for the Local Users stations.

G. **Reference User Station validation**

The reference user station located at the EUMETSAT central site is the model of a typical receiving station used by all other Local Users stations of the Metop system in support of the Metop Local Mission. The validation of MMAM processing by this station is foreseen for the second half of May 2012. It will be done by manually injecting HRPT TM stream, containing the MMAM, into the station (isolated from the rest of the mission control facilities) and checking the proper ingestion and processing of the data by the station; that includes proper pointing of the antenna to the AOS location derived from the TLE in the MMAM and proper geolocation of the scientific data interpolating the ephemeris contained in the MMAM. The Metop-B HRPT data shall be generated by the simulator during a dedicated simulation campaign.

H. **NOAA validation**

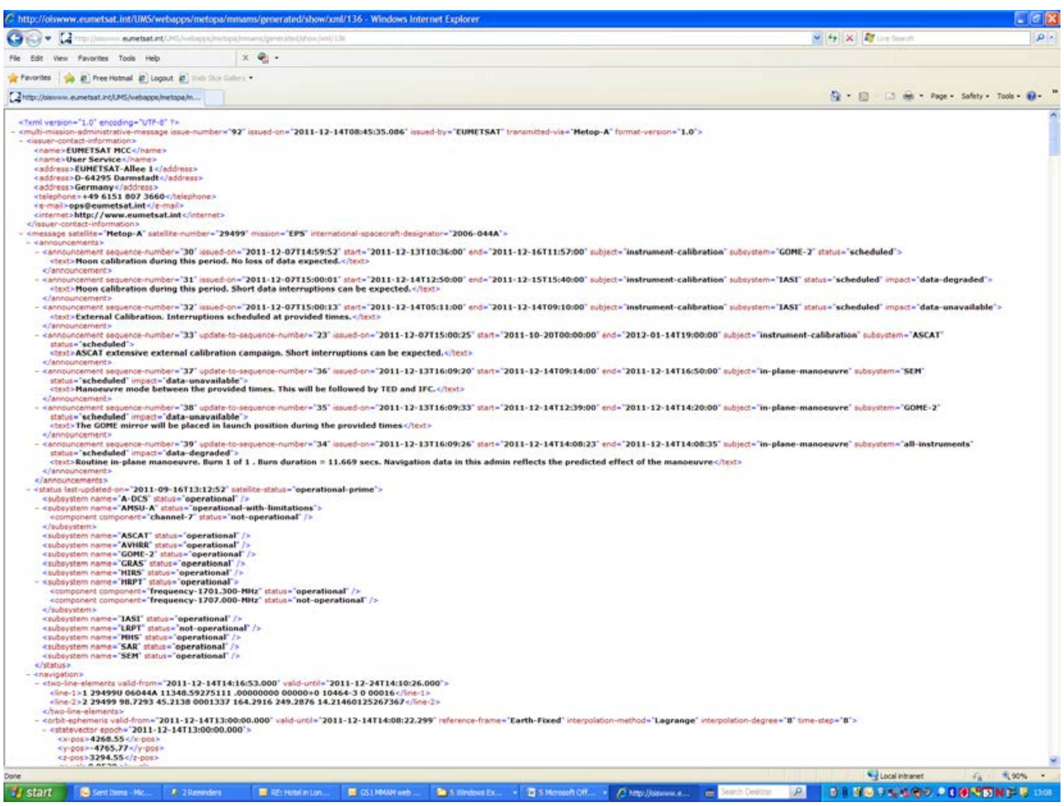
NOAA shall extract OBTUTC correlation parameters from the MMAM for Metop-B (as done from Metop-A from the admin message) for proper time-stamping of the scientific data: Metop-B X-band simulated TM, containing the MMAM, shall be transferred to NOAA using the operational link and proper ingestion in the NOAA processing chain shall be verified. This exercise is foreseen in June/July 2012.

I. **In-flight validation**

Assuming a nominal Metop-B launch in mid-July 2012, first MMAM upload on board is foreseen within the first week of operations. The MMAM will be there received by the Reference User Station which will validate the proper reception and de-commutation from the HRPT data stream. Local Users will also have the opportunity of validating their updated on-ground system. Local Users are expected to have completed the validation activity before end of Metop-B commissioning, six month after launch.

VI. Example of MMAM Message

An example of the MMAM message as it appears in a browser is given here-below



```
<?xml version="1.0" encoding="UTF-8" ?>
- <multi-mission-administrative-message issue-number="92" issued-on="2011-12-14T08:45:35.086" issued-by="EUMETSAT" transmitted-via="Metop-A" format-version="1.0">
 - <issuer-contact-information>
    <name>EUMETSAT MCC</name>
    <name>User Service</name>
    <address>EUMETSAT-Allee 1</address>
    <address>D-64295 Darmstadt</address>
    <address>Germany</address>
    <telephone>+49 6151 807 3660</telephone>
    <e-mail>ops@eumetsat.int</e-mail>
    <internet>http://www.eumetsat.int</internet>
   </issuer-contact-information>
 - <message satellite="Metop-A" satellite-number="29499" mission="EPS" international-spacecraft-designator="2006-044A">
  - <announcements>
   - <announcement sequence-number="30" issued-on="2011-12-07T14:59:52" start="2011-12-13T10:36:00" end="2011-12-16T11:57:00" subject="instrument-calibration" subsystem="GOME-2" status="scheduled">
      <text>Moon calibration during this period. No loss of data expected.</text>
     </announcement>
   - <announcement sequence-number="31" issued-on="2011-12-07T15:00:01" start="2011-12-14T12:50:00" end="2011-12-15T15:40:00" subject="instrument-calibration" subsystem="IASI" status="scheduled" impact="data-degraded">
      <text>Moon calibration during this period. Short data interruptions can be expected.</text>
     </announcement>
   - <announcement sequence-number="32" issued-on="2011-12-07T15:00:13" start="2011-12-14T05:11:00" end="2011-12-14T09:10:00" subject="instrument-calibration" subsystem="IASI" status="scheduled" impact="data-unavailable">
      <text>External Calibration. Interruptions scheduled at provided times.</text>
     </announcement>
   - <announcement sequence-number="33" update-to-sequence-number="23" issued-on="2011-12-07T15:00:25" start="2011-10-20T00:00:00" end="2012-01-14T19:00:00" subject="instrument-calibration" subsystem="ASCAT"
      status="scheduled">
      <text>ASCAT extensive external calibration campaign. Short interruptions can be expected.</text>
     </announcement>
   - <announcement sequence-number="37" update-to-sequence-number="36" issued-on="2011-12-13T16:09:20" start="2011-12-14T09:14:00" end="2011-12-14T16:50:00" subject="in-plane-manoeuvre" subsystem="SEM"
      status="scheduled" impact="data-unavailable">
      <text>Manoeuvre mode between the provided times. This will be followed by TED and IFC.</text>
     </announcement>
   - <announcement sequence-number="38" update-to-sequence-number="35" issued-on="2011-12-13T16:09:33" start="2011-12-14T12:39:00" end="2011-12-14T14:20:00" subject="in-plane-manoeuvre" subsystem="GOME-2"
      status="scheduled" impact="data-unavailable">
      <text>The GOME mirror will be placed in launch position during the provided times</text>
     </announcement>
   - <announcement sequence-number="39" update-to-sequence-number="34" issued-on="2011-12-13T16:09:26" start="2011-12-14T14:08:23" end="2011-12-14T14:08:35" subject="in-plane-manoeuvre" subsystem="all-instruments"
      status="scheduled" impact="data-degraded">
      <text>Routine in-plane manoeuvre. Burn 1 of 1 . Burn duration = 11.669 secs. Navigation data in this admin reflects the predicted effect of the manoeuvre</text>
     </announcement>
    </announcements>
  - <status last-updated-on="2011-09-16T13:12:52" satellite-status="operational-prime">
     <subsystem name="A-DCS" status="operational" />
   - <subsystem name="AMSU-A" status="operational-with-limitations">
      <component component="channel-7" status="not-operational" />
     </subsystem>
     <subsystem name="ASCAT" status="operational" />
     <subsystem name="AVHRR" status="operational" />
     <subsystem name="GOME-2" status="operational" />
     <subsystem name="GRAS" status="operational" />
     <subsystem name="HIRS" status="operational" />
   - <subsystem name="HRPT" status="operational">
      <component component="frequency-1701.300-MHz" status="operational" />
      <component component="frequency-1707.000-MHz" status="not-operational" />
     </subsystem>
     <subsystem name="IASI" status="operational" />
     <subsystem name="LRPT" status="not-operational" />
     <subsystem name="MHS" status="operational" />
     <subsystem name="SAR" status="operational" />
     <subsystem name="SEM" status="operational" />
    </status>
  - <navigation>
   - <two-line-elements valid-from="2011-12-14T14:16:53.000" valid-until="2011-12-24T14:10:26.000">
      <line-1>1 29499U 06044A 11348.59275111 .00000000 00000+0 10464-3 0 00016</line-1>
      <line-2>2 29499 98.7293 45.2138 0001337 164.2916 249.2876 14.21460125267367</line-2>
     </two-line-elements>
   - <orbit-ephemeris valid-from="2011-12-14T13:00:00.000" valid-until="2011-12-14T14:08:22.299" reference-frame="Earth-Fixed" interpolation-method="Lagrange" interpolation-degree="8" time-step="8">
    - <statevector epoch="2011-12-14T13:00:00.000">
        <x-pos>4268.55</x-pos>
        <y-pos>-4765.77</y-pos>
        <z-pos>3294.55</z-pos>
```


Figure 5 Example of Metop-A MMAM message as XML view: announcements and status

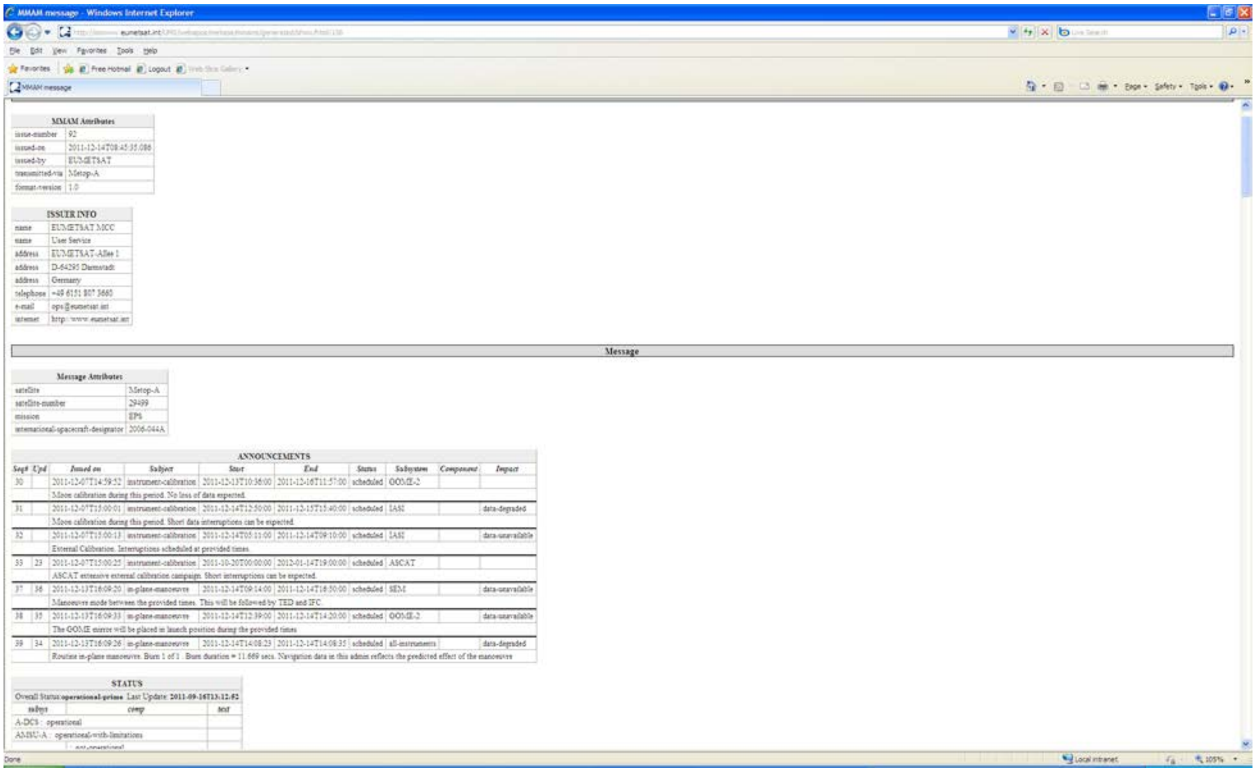


Figure 6   Example of a MMAM message as html view

VII. Conclusion

The overall EPS system is a highly reliable, complex system designed to be available 7 days a week, 24 hours per day. Introducing the MMAM into operational service within EPS was a challenging task, as MMAM impacts the operations of the ground segment, the spacecraft and the data storage at the same time. MMAM is designed to deliver a well-organized amount of information to users about satellite platform, instruments, data processing, and ground system activities in order to substantially facilitate the user exploitation of the EUMETSAT-distributed meteorological and climate data. MMAM has been certified for operational use in time for the Metop-B launch.
The MMAM usage is being considered for all upcoming LEO missions operated by EUMETSAT. It is planned to use only the new MMAM for Metop-B, slated for launch for mid-July 2012. As soon as Metop-B is declared prime Metop satellite, Metop-A will start using the new MMAM too.

The MMAM has arrived and it is here to stay.

Acknowledgments

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References

While the present paper describes the MMAM introduction into system operations, the following paper describes the MMAM usage benefits for the geo-location of instrument data acquired from LEO missions:

[1]Damiano A., Righetti P.L., Soerensen, A."An XML-based MMAM for LEO Earth-Observation Satellites," *SpaceOps 2008 Conference, Heidelberg, Germany*, May 12-16, 2008, AIAA 2008-3323,

This is the publicly available description of the MMAM:

[2]EUMETSAT Flight Dynamics Team,"Multi-Mission Administrative Message User's Guide", EUM/OPS/TEN/07 v2C, 2011. A PDF-formatted version of this document can be downloaded from the following internet page http://www.eumetsat.int/Home/Main/DataAccess/DirectDissemination/SP_20110617101838130?l=en

The following document provides an introduction to the EARS system, the largest community of Metop Local users and thus the main user of the MMAM.

[3]EUMETSAT EARS Team, "EARS Operational Service Specification", EUM/OPS/SPE/01/0839, v4, March 2009 http://www.eumetsat.int/Home/Main/Satellites/GroundNetwork/EARSSystem/Index.htm?l=en

The following document provides an introduction to the Metop system:

[2]EUMETSAT"Operational Service Specifications", EUM/OPS/SPE/09/0810 v1D, July 2009. A PDF-formatted version of this document can be downloaded from the EUMETSAT internet page http://www.eumetsat.int/ and then navigating the "satellite" tab towards "Metop" and "Resources",