Techniques and processes for pre-launch characterisation of new instruments

Dieter Klaes and Jörg Ackermann

EUMETSAT
Eumetsat Allee 1, D-64295 Darmstadt, Germany
dieter.klaes@eumetsat.int
joerg.ackermann@eumetsat.int

ABSTRACT
This paper discusses the techniques and processes related to the pre-launch characterisation of new instruments on meteorological satellites. It was considered to be beneficial for the seminar to provide a general overview of the whole process related to the preparation of new systems. Hence the paper covers the whole long-standing activities from the identification of the requirements, the development activities, the preparations for launch and operations, and related testing until commissioning activities. It includes the discussion of the consultation of Users, the resulting generation of User requirements, how this yields to payload proposal and requirements, and finally the development process. Selected activities are illustrated with examples from current and past space projects.

1 Introduction

EUMETSAT delivers global Earth observations and services to Users with a fleet of satellites in geostationary and polar orbits. Together with global partner organisations EUMETSAT provides additional observations for forecast and climate monitoring services on a number of components of the Earth System, like ocean parameters, cryosphere information, and surface parameters in general.

EUMETSAT is a User driven organisation, and a fruitful and continuous dialogue between its users and the stakeholders for the development and implementation of the satellite observing system components contributes to the successful implementation of new programmes (EUMETSAT, 2014a). Consequently, the implementation of observation systems and related services is strictly based on the requirements identified by and collected from the User community. During the whole lifecycle of a programme, EUMETSAT is maintaining the interface to its users and is responsible for the collection of the requirements and their formulation as end user and system level requirements. Thus, EUMETSAT is responsible for the system design and development as well as for the procurement of the ground segment and the launch services. After successful launch and commissioning, EUMETSAT has the responsibility for the operation of the full satellite systems and the ground infrastructure. In achieving this, EUMETSAT assures the delivery of data, products and support services to users.

EUMETSAT has a long-term partnership with ESA, who is developing the satellites and most instruments, procures the recurrent spacecraft, and also supports the launch campaigns and commissioning activities.

A space project is a complex process with several phases, which proceed the project towards and beyond operational implementation. A distinct number of phases, which follow standard procedures like ECSS (European Cooperation for Space Standards (ECSS, 2014), have to be successfully completed. This comprises:

- Mission Analysis and Identification of Requirements (Phase 0),
- Feasibility Studies (Phase A),
- Preliminary Definition (Phase B),
- Detailed Definition (Phase C),
- Production and Ground Qualification [Segment] Testing (Phase D),
- Utilisation [Operations] (Phase E)
- Disposal (Phase F) [De-Orbiting].

2 Identification of requirements and feasibility studies

The first step for a new programme is to identify the potential users to address their needs , to assess the feasibility of related observations and applications, and to formulate the resulting requirement specifications. With the increasing complexity of systems and the increasing number of application areas and observations required, these steps need long term preparation. Nowadays one has to think about follow-on programmes already before the current programme has launched its satellites. Two examples: The User Consultation Process for the Meteosat Third Generation (MTG) Programme (EUMETSAT, 2014b; ESA, 2014a; Bensi et al., 2004), currently under development for a launch in the 2018/2019 timeframe, was kicked-off in 2001 [one year before the launch of the first Meteosat Second Generation Satellite (MSG-1) in 2002],the same is the case for EUMETSAT Polar System follow on, first named Post-EPS (EUMETSAT, 2014c; ESA, 2014b; CGMS, 2009), where the User Consultation process began in 2005, one year before the launch of Metop-A in 2006.

The need to start the requirements identification process very early means that a large number of issues must be projected into the (rather far) future. One has to assess present applications, and project them into the future, e.g. what performance NWP models will have in 10-15 years from now: what will be their grid size, which new parameters will need to be predicted (and can be predicted?) or w hat is the required timeliness? Particular thought needs to be put into the identification of extended or new applications, and the observation needs for those have to be assessed and identified. So in summary, the following key questions have to be addressed:

- What are the applications?
- Who are the Users? Are there Users?
- What parameters will be needed?
- What are the observation requirements?
- Which (existing or planned) missions can satisfy the requirements?
- Where are gaps?
- Which other developments exist?

This list is not exhaustive but illustrates the bandwidth of considerations to be taken. To find and assess sources of information is essential. This starts from analysing heritage missions and leads to the analysis of documentation and data bases on other current and future missions and their performance. Fortunately nowadays a number of such documentation and databases already exist, most of them established in previous requirements analysis processes. Many of these are developed and administered by WMO (World Meteorological Organisation) and can be accessed via the WMO web page (WMO, 2014). To name some examples:

- The Rolling Requirements Review data base for meteorological observations (RRR), (WMO, 2014).
- The Observing Systems Capability Analysis and Review Tool (OSCAR), which contains quantitative user-defined requirements for observation of physical variables in application areas of WMO (i.e. related to weather, water and climate). OSCAR also provides detailed information on all Earth observation satellites and instruments, and expert analyses of space-based capabilities. (WMO, 2014).
- The CEOS data base, provided and maintained for CEOS by ESA; The information presented in the CEOS Handbook is a strongly condensed summary of the information provided in the CEOS Missions, Instruments and Measurements (MIM) Database (CEOS, 2014).
- The gap analysis for GCOS (Global Climate Observing System), an analysis of observational gaps for the derivation of Essential Climate Variables, (Bizzari, 2011, on WMO web-page).

There are many other sources of information, but it would be beyond the scope of this paper to address them all.

As already pointed out, the major activities in these phases are the identification of User needs and the Mission analysis (Phase 0), and to study the feasibility of the candidate missions (Phase A). For this process EUMETSAT has a process model (EUMETSAT, 2008), which capitalises on the experience made within the MTG preparations (essentially between 2001 – 2005) and was used for the Post-EPS (renamed to EPS Second Generation EPS-SG) Phase 0/A activities. It involves the Users and experts (for specific application areas, for measurement systems, etc.) in the field from partner organisations and academia. Studies are initiated to assess observation capabilities and their possible impact on applications, and the feasibility of observations and applications. In the case of MTG, two Application Expert Groups (EUMETSAT, 2001) were established, one on Global and Regional Numerical Weather Forecasting and one on Nowcasting, which together were expected to cover the identified key applications of MTG. These Expert Groups conducted Position Papers for their respective subject, formulating the EUMETSAT User needs, which were then discussed by Remote Sensing experts and stakeholders in the MTG Mission Expert Team. Numerous meetings and workshops were held to conclude on Mission and Observation requirements, and to set up a draft user requirements for the candidate missions. For Post-EPS (EPS-SG), additional Application Expert Groups (EUMETSAT, 2005) were formed, given further application areas on Operational Oceanography, on Atmospheric Chemistry, on Carbon Cycle Protocol Monitoring and Air Quality, on Land Surface Analysis at large scale, and on Climate Monitoring. From the resulting Position Papers an initial list of instruments constituting the payload of the future satellites, was identified. To come up with such list and to identify the relevant missions, several aspects have to be taken into account:

- Heritage instruments for mission continuity
- Mission continuity, but also improvements and new instruments, challenging new technology
- Research missions, mature enough to fill identified gaps
- Complementary mission contributions by partners.

The process can be summarized as follows:

First Step: Initial formulation of potential user requirements in terms of

- Accuracy
- Spatial sampling

- Temporal sampling
- Delivery delay (timeliness)

For these Threshold (minimum level of usefulness), Breakthrough (expected to make a delta improvement in the targeted service) and Objective (observation goal) level, potential requirements need to be formulated.

This is the basis for the Application Expert Group discussions and the subsequent User Consultation. Each of the potential user requirements is initially assessed:

Second Step:

- Broad identification of suitable observation techniques
- Identification of heritage/pre-cursor research instruments or missions
- Estimation of the expected performance in the threshold-objective range

The next step consists the generation of mission requirements:

Third Step:

- Candidate missions are identified and grouped
- The targeted data levels are identified and defined
- Related observation requirements are identified in terms of spatial and spectral resolution, radiometric performance etc.
- User services and requirements related to non-observation issues are identified and defined.

Fourth Step: Technical Requirements

is essentially worked on with ESA, in deriving the technical requirements for sensor system studies, and identifying and conducting feasibility studies for the space system. Scientific and technical studies are run in this phase to assess feasibility and possible impact of new/improved instruments.

The described process is an iterative process, with all participants interacting and iterating, including EUMETSAT delegate bodies, involving a number of User Consultation Workshops (e.g., three workshops were held so far in the case of Post-EPS). The final results include a System concept, Operations concept, Ground Segment concept, and the Space Segment concept. They are decision aids for EUMETSAT delegate bodies to select the payload complement and the satellite configuration. The resulting concepts and documentation, in particular the draft End User Requirements Document, are input to the programme development phase (starting with Phase B).

3 Development activities and preliminary definition

The development activities start with the Phase B activities. The baseline for the missions is defined in the End User Requirements Document (EURD), which has been approved which is an outcome of the Phase 0/A activities, and is owned by the EUMETSAT Council. From this all system documents will be derived, in particular the System Requirements and sub-system documents like Ground Segment Requirements etc. In particular, specifications are prepared for the processing chains of the satellite payload with prime focus on level 0 and level 1 processing, but also for the processing of selected geophysical products (Level 2).

As indicated above, ESA is developing in parallel the space segment. The instruments are either developed as part of the satellite development programme, or are provided by partners. For example, the IASI instrument on EPS/Metop and the IASI-NG instrument on Metop-SG are provided under co-operation by the French Space Agency (CNES). Other instruments are developed under third party activities, and are flown and operated on the spacecraft, like the Sentinel-4 (MTG) and Sentinel-5

(Metop-SG) instruments, which are part of development activities in the frame of the Copernicus programme.

Following the system approach laid down in a System Development Plan (SDP), a set of specifications needs to be established, which are the basis for the industrial development of the processors, and also provide the tools and data for testing the system and the processing chains. As an example, in EPS-SG, the approach is to provide for each instrument data processing chain:

- Algorithm Theoretical Basis Documents (ATBD)
  specifying the scientific approach for the processing of the instrument data
- A set of PGS/PFS/ADS:
    - In the Product Generation Specification (PGS) the full processing chain with all dependencies, input/output and auxiliary data, the processor logic etc. is specified;
    - In the Product Format Specification (PFS) the complete product format, including the measurement data records, but also all meta data, and auxiliary data, which are required to fully characterise the product is described;
    - In the Auxiliary Data Specification (ADS) all auxiliary data, static and dynamic, which are required to process the respective instrument data, is given.
- A set of prototype processors, which are representative for the product processing specification and are able to produce reference data in order to allow the validation of the operational processing chains.

In the frame of the instrument development activities, the instrument specifications are established by:

- Instrument Requirements Specification (IRS)
- Payload Data Simulators (PDS) which are developed to provide simulated data as produced by the instrument
- Ground Processor Prototypes (GPP) to simulate and demonstrate the level 0 and level 1 algorithms for each instrument.

Instrument and product test data are generated in order to allow the testing of the system, in particular the throughput and the timeliness, but also allow assessing the performance of the system and the fulfilment of user requirements. As an example Figure 1 and Figure 2 show results from test data activities in the frame of EPS-SG/Metop-SG for the Microwave Sounding Instrument (MWS), which is the follow on mission for the MHS and AMSU-A instruments on EPS/Metop. In Figure 1 the spatial sampling of the channels based on the requirements established in the EURD are plotted . Figure 2 shows the validation of established test data for the MWS channel 11 (57.2 GHz) in comparison with AMSU-A channel 9, the comparable channel on the heritage instrument (Bennartz and Fell, 2014).

In general, product processing chains are developed by industry in the framework of the Ground Segment development using the specifications, mentioned above (PGS, PFS, ADS, and ATBD etc.). From the customer side, a number of instruments are put into place to support these activities and in particular to provide advice to the Programmes. This includes studies e.g. to generate test data for verification and validation purposes, but also Advisory Groups for the programmes, Science or Mission Advisory Groups (SAGs, MAGs), related to individual instruments and their development, including the processing chains. Often the generation of a science plan is envisaged and allows to assure not to overlook issues. Examples of such groups are the IASI Sounding Science Working

Group (ISSWG, reference to CNES web page), or the MTG IRS science team (MIST), which was transformed into the MTG IRS MAG. Task forces can support these activities in order to address specific urgent issues.

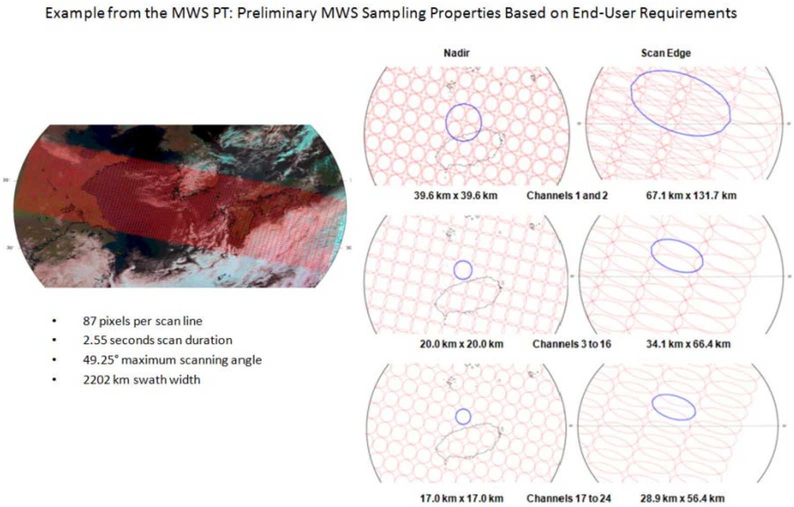

Figure 1: Preliminary sampling of the Microwave Sounding Instrument planned for EPS-SG derived from the End User Requirements.

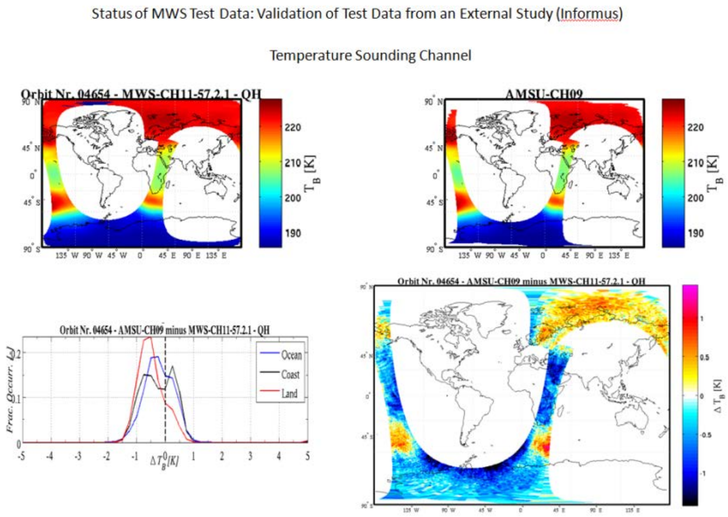

Figure 2: Test data for the MWS channel 11 (57.2 GHz) in comparison with AMSU-A channel 9, the comparable channel on the heritage instrument.

In the frame of the Advisory Group activities advice is sought also for the instrument development, and instrument characterisation and testing is performed in the frame of the industrial development. The characteristics of the instruments are determined in numerous tests, in particular also during thermal vacuum tests to characterise the instrument under space like conditions. All activities and measurements of the instruments are documented in a calibration handbook (calibration log book). Additional documentation includes the calibration algorithms, the calibration parameters and the data from the tests, in particular from laboratory characterisation and external calibration.

The so called End Item Data Package (EIDP) is delivered with the instrument and contains all documents, including

- Characterisation data, e.g. antenna patterns
- The Calibration hand book,
- Thermal Vacuum data from the satellite
- Relevant Drawings and photos,
- All test reports

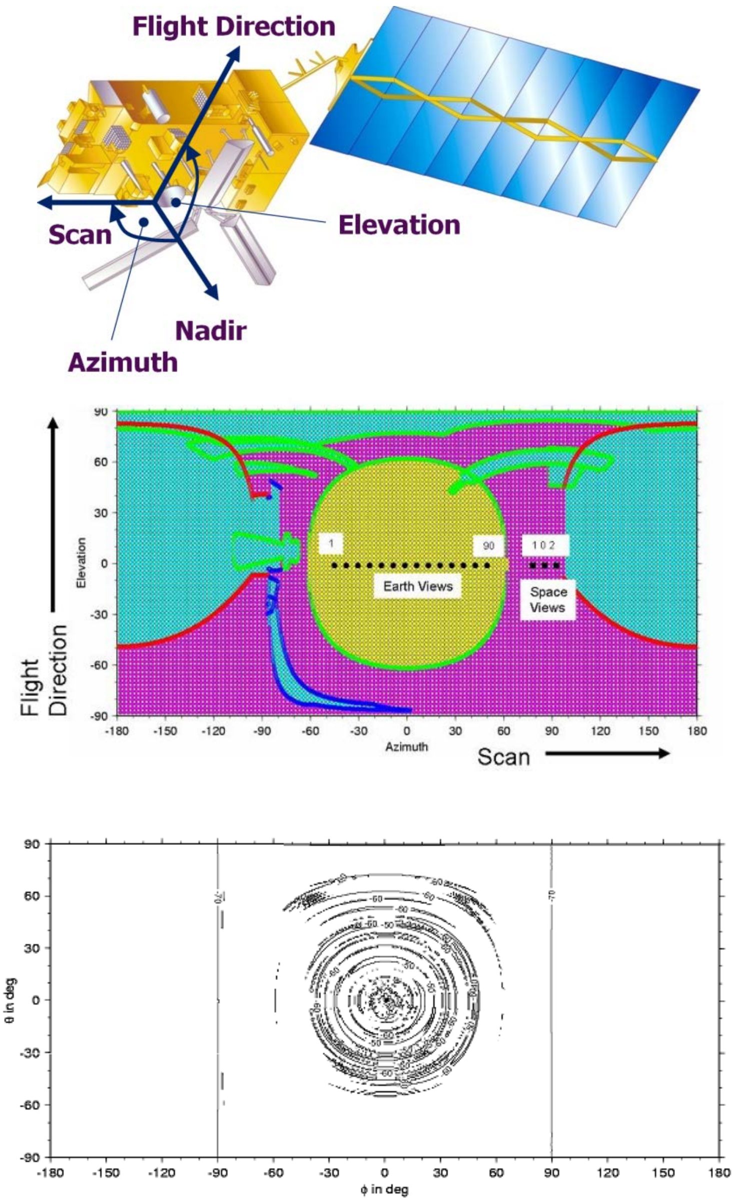

Figure 3: Steps to compute antenna corrections for microwave instruments: the satellite geometry (upper) is transformed to the instrument viewing geometry (middle) and convolved with the actual antenna pattern (lower) on the assumption of a distinct temperature distribution (represented by the different colours in the mid plot); the example is for the Microwave Humidity Sounder on Metop-A.

From the above mentioned documents the level 0, level 1 algorithms are deduced. Necessary correction algorithms and instrument auxiliary data are derived from the data gained during the pre-launch testing. As an example for a correction algorithm, Figure 3 shows the steps to compute the antenna correction of the MHS instrument on Metop-A: a geometrical satellite model is transformed into a coordinate system, whose origin is the MHS antenna system. The temperature distribution surrounding the MHS antenna system comprises of three 'components', i.e. radiations from the Earth, the space and the satellite. This distribution is convolved with the pre-launch determined antenna pattern to retrieve the antenna efficiencies for the individual Earth view directions, and the space view correction coefficients. Figure 4 shows the calculated antenna corrections to be applied to the operational instrument calibration algorithm.

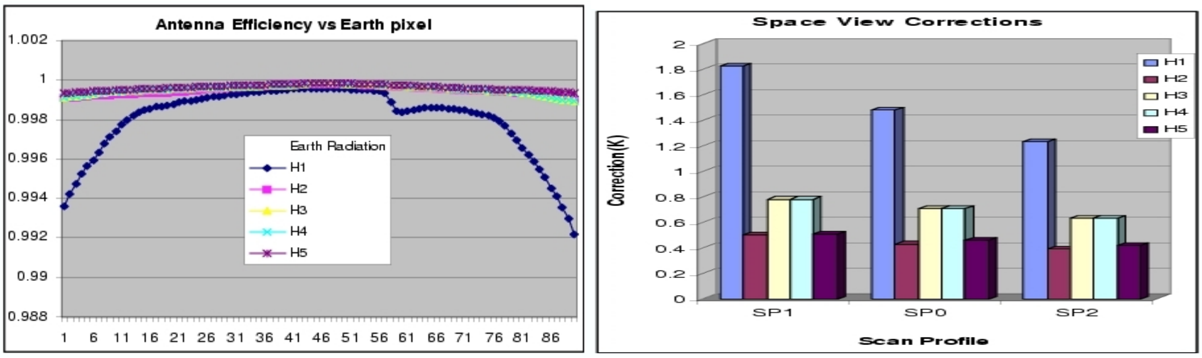

Figure 4:Antennaefficiencies for the Earth views (left) and resulting corrections of the space views forthe Mircowave Humidity Sounder (MHS) on Metop-A.

4 Operations preparation and ground segment testing

To prepare for launch and exploitation of the data the whole system undergoes testing, with the delivered operational processing algorithms and related test data sets, which are characteristic for the subsequent real space data.

Testing includes testing the functionality and throughput performance, for this purpose of verification, the test data do not necessarily need to be fully scientifically representative. However, to validate in an early stage the fulfilment of product requirements, realistic test data are necessary, whereas this part of the testing can be done off line.

In a further step of system testing, all processing chains need to be tested in full operational load; this includes both global and regional/local processing chains.

Before the satellite launch, it is desirable to conduct rehearsals for the data processing as well (in spite one only can finally judge the performance with the real data!), in order to assess the readiness for launch and the subsequent SIOV (Satellite in Orbit Verification) and Calibration and Validation Phase. As an example the rehearsal steps done for the Metop-B launch preparation are outlined below for ATOVS/AVHRR:

- Metop-B data were simulated by Metop-A data
- Corresponding Metop-B processing nodes in EPS Ground Segment 2 have been configured to simulate a true Metop-B processing as close as possible. This means that the incoming Metop-A Level 0 data stream is processed with the specifications of the Metop-B instrument suite. Validation was performed as in the Metop-A Commissioning Phase using products processed by an off-line reference prototype.

- The simulated data covered three orbits starting at about 5:51, 7:33, and 9:15 UTC, respectively, on 25th June 2012.

Example of core parameters tested for ATOVS/AVHRR Level 1B products:

- Calibrated Earth View Radiances
- Geolocation (lat, lon)
- Satellite and Solar Azimuth and Elevation
- Surface Type (for AMSU, MHS, and HIRS only)
- Surface Altitude (for AMSU, MHS, and HIRS only)

```
#################################################################
###                                                           ###
###     AMSU Calibration Parameters for A1-108 and A2-106     ###
###              Onboard Metop-B                              ###
###                                                           ###
###     version 03 Author: Joerg Ackermann, EUMETSAT          ###
###                                                           ###
#################################################################
03   ; version number (cal parameter id in 1B dataset)
2011 ; year of the version
259  ; day of year of the version.
## Values for Fundamental Constants ##
## Speed of light m/s ##
299792458
## Planck constant J s ##
6.6260755e-34
## Boltzmann constant J/K ##
1.380658e-23
## First & second radiation constants mW/(sqm.ster.cm^-4) & K/cm^-1 ##
 1.191044e-05,1.438769
## Brightness temperature of space at AMSU frequencies degK ##
2.73
## 15 Central wavenumbers ##
0.793897,1.047421,1.677830,1.761235,1.787785,1.814590,1.832608,1.851295
1.911001,1.911001,1.911001,1.911001,1.911001,1.911001,2.968887
## Band Correction Coefficients a,b for each channel --
## used to modify TW to give an effective temperature T'W for use
## in the Planck function.
0,1
0,1
0,1
0,1
0,1
0,1
0,1
0,1
0,1
0,1
0,1
0,1
0,1
0,1
0,1
## Nominal space & internal target viewing angles
-83.333,180.0
-81.667,180.0
-80.000,180.0
-76.667,180.0
# lunaflag for turning on(1)/off(0) moon
 1
# threshold angle for moon contamination in degrees * 100
 390
###############################################################################
## AMSU-A1 DATA S/N 108 (METOPB) ##
## ID of instrument
29
# Selected position of space view for calibration 0->3 (will be selected during IOV)#
0
# Slope and offset for counts to antenna posn in deg, A1-1 and A1-2 (adapted to Tab. 10.0.1 values)#
-0.021973, 51.36
-0.021973, 46.06
# Antenna Pos error allowed in deg for cal and Earth views, A1-1 and A1-2 #
1.3,0.33
1.3,0.33
# IWT PRT count to temperature in degK conversion coefficients (best fit of data in Tab. 4.1.1)#
  254.8997   1.6486870E-03   5.9915850E-09   3.0658910E-14
  254.7430   1.6523180E-03   6.0197870E-09   2.9858890E-14
  254.6643   1.6539240E-03   5.9841080E-09   2.9776300E-14
  254.8877   1.6574190E-03   5.9341200E-09   3.1709220E-14
  254.1918   1.6465040E-03   6.0760720E-09   2.8224180E-14
  255.6000   1.6162670E-03   6.1592160E-09   3.7101130E-14
  254.7424   1.6486220E-03   5.9308110E-09   3.0390770E-14
  255.5381   1.6180470E-03   6.1058810E-09   3.6427240E-14
  255.4768   1.6296350E-03   6.2061300E-09   3.8552680E-14
  254.4784   1.6470340E-03   5.9518710E-09   2.9568630E-14
# Weight coefficients for each PRT, A1-1 and A1-2 #
1,1,1,1,1
1,1,1,1,1
# Reasonable PRT temp limits in degK (min,max), A1-1 and A1-2 #
258.15.313.15
```

Figure 5: Calibration parameters for Metop-B AMSU as provided pre-launch (Ackermann, 2012).

Full validation reports were produced based on a full production day and a dedicated Product Validation Review Board was held to assess the outcome of the test.

One important activity at this time is to assure that the users are involved and early access is given to the data as far as possible. For this purpose, potential external Cal/Val partners are identified who will receive the data as soon as they are suitable at an early stage in the commissioning phase. This allows for both, a fast assessment of data quality from a user point of view and possibly already an estimate of the impact of the new data stream on e.g. NWP model output. The feedback from these users is an invaluable asset to conclude early on the demonstrational and pre-operational state of a product and allows shortening the commissioning of products significantly. With this, most of the EPS products were available to users already a few weeks after launch. An additional pre-requisite to accomplish this is that instrument characteristics and correction parameters are made available early to users as well. This was done for EPS, an example is shown below for instrument calibration parameters of AMSU onboard Metop-B (Figure 5).

Close cooperation was maintained with the partners. In particular with NOAA the co-ordination of the calibration parameters and the instrument characteristics for the Level 0 to Level 1 processing were closely coordinated, so that on both sides of the Atlantic the same set of parameters is used.

5 Commissioning activities

Commissioning activities are out of the scope of this presentation (they take place after launch) and are therefore only mentioned for completeness. In principle, all activities rehearsed before launch are conducted, including the SIOV and Cal/Val Phase. It is worth to mention that for Metop commissioning, the Cal/Val phase, which nominally only starts after completion of SIOV, was run in parallel as the product quality allowed to do so Thus, the Cal/Val Partners identified beforehand were fully involved in the commissioning activities. Metop-B could be handed over to operations already in January 2013, and became the prime operational satellite in April 2013. Commissioning ended in July 2013.

6 Summary and conclusion

The preparation for a space system is a long process and requires a thorough scheduling. Information to Users and User involvement is crucial. A full user consultation process, followed by a defined development process with user and expert involvement is mandatory. Furthermore, good cooperation between all stakeholders is required. It is desirable to deliver the data and products to users as early as possible, in order to allow the maximum exploitation of the system.

References

Bennartz, R., and F. Fell, 2014: Generation of test data for the EPS-SG passive microwave missions (TESPaMM) EUMETSAT ITT 13/206888 Final Report, 134 pp.

Bensi, P., D. Aminou, J.-L. Bézy, R. Stuhlmann, A. Rodriguez and S. Tjemkes, 2014: Overview of Meteosat Third Generation (MTG) Activities; *Proceedings of the Second MSG RAO Workshop (ESA SP-582). Salzburg, Austria, 9–10 September 2004. Organised by ESA, in cooperation with EUMETSAT. Editor: H. Lacoste,* p.37, 2004ESASP.582...37B

CGMS, 2009: http://www.cgms-info.org/documents/documents-cgms/cwpt_280~1.pdf

ESA, 2014a: https://directory.eoportal.org/web/eoportal/satellite-missions/m/meteosat-third-generation

ESA, 2014b: https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg

ECSS, 2014: www.ecss.nl

EUMETSAT, 2001: http://www.eumetsat.int/website/wcm/idc/idcplg?IdcService=GET_FILE&dDocName=pdf_mtg_ucw1_01&RevisionSelectionMethod=LatestReleased&Rendition=Web

EUMETSAT, 2005: http://www.eumetsat.int/website/wcm/idc/idcplg?IdcService=GET_FILE&dDocName=pdf_mtg_ucw2_16&RevisionSelectionMethod=LatestReleased&Rendition=Web.

EUMETSAT, 2008: Process Model for Project Phases 0 and A in EUMETSAT, *EUM/PPS/DOC/08/0118,* 32pp.

EUMETSAT, 2014a:http://www.eumetsat.int/website/home/AboutUs/WhoWeAre/Strategy/index.html

EUMETSAT, 2014b: http://www.eumetsat.int/website/home/Satellites/FutureSatellites/MeteosatThirdGeneration/index.html

EUMETSAT, 2014c: http://www.eumetsat.int/website/home/Satellites/FutureSatellites/EUMETSATPolarSystemSecondGeneration/index.html

WMO, 2014: www.wmo.int