Calibration and Validation of Metop/ATOVS and AVHRR products

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Abstract

The first of three morning-orbiting Metop satellites will be launched in the spring of 2006. It will embark the AVHRR, AMSU-A, and HIRS instruments, such as are already operating on the current series of NOAA satellites. Metop will also embark the Microwave Humidity Sounder (MHS), which replaces the AMSU-B instrument. In collaboration with our partner organisations, and in particular with the support of NOAA, EUMETSAT has planned out an extensive list of activities to calibrate ATOVS and AVHRR products from Metop and to establish and monitor their quality. A Calibration and Validation facility has been procured, and additional tools will also be made available to select users to extract, visualise and carry out simple analyses on these products.

Introduction

Currently scheduled to launch in April 2006, the first Metop satellite to be launched (FM-2[1]) will embark the AMSU-A, MHS, HIRS/4, AVHRR/3, IASI, GOME-2, GRAS and ASCAT instruments that will measure numerous properties of the Earth's surface and atmosphere. The first four of these instruments are of the ATOVS and AVHRR instrument suite. They have been operated by NOAA for up to three decades in various incarnations and are the subject of this paper.

Cal/Val activities fall into two major categories. The first category of activities is the core analysis, involving initial checks and ongoing monitoring. These will tune the processing and demonstrate performance against the applicable user requirements. In the second category, more detailed analyses will be carried out on a lower priority basis to refine the processing and to improve the understanding of the product quality. Through this latter category of activities, EUMETSAT will demonstrate its commitment both to continual improvement in the products, and to building upon state-of-the-art scientific results.

Extensive planning has been carried out to prioritise and schedule the pre-launch preparatory and post-launch analysis activities to calibrate/retrieve the products, to test their internal consistency, and to validate them against independent reference measurements. This work has benefited from the experience at NOAA via numerous interactions for input and review. Additional direction was taken from work done on related instruments such as ENVISAT

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[1] This will be renamed "Metop-A" once in-orbit.

(e.g. Robinson 2000) and EUMETSAT's experience with the METEOSAT series of satellite instruments.

This paper will discuss the activities to be carried out for product Calibration and Validation (Cal/Val)[2] as derived from the objectives and priorities. It describes the CVF as well as a selection of tools that are available to the user community, and discusses a logical schedule.

Objectives and Priorities

The objectives for ATOVS and AVHRR Cal/Val are to provide data that meet the user requirements for product accuracy after the commissioning phase, and to achieve state-of-the-art performance and accuracy throughout the mission lifetime. This involves converting raw instrument data into geo-located products expressed in terms of recognised physical units. It also requires testing and revision of processing algorithms and required databases. Finally, it also calls for the determination of product quality, in terms of precision and accuracy, guaranteed over the mission lifetime, and assessed by multiple independent means (i.e. cross-checked against similar instruments).

Two sets of criteria were employed to arrive at an overall determination of activity priorities, and these priorities have subsequently been employed to schedule tool procurement activities and to sequence future validation analyses. The set of objective criteria includes the EPS End User Requirements Document (EURD) product priority (See rightmost column in Table 1 below), product accuracy requirements, cost, and feasibility. More subjective criteria include geographic coverage, temporal coverage and instrument type. Based upon these criteria, activities are defined to fall into one of four categories, as explained below:

- *Mandatory* activities are critical to the completion of the Commissioning phase objectives. Anomalies affecting these shall be handled as blocking anomalies, and their correction shall be given priority over any planned activity.

- *Important* activities should be completed during the Commissioning phase. Anomalies affecting them shall be given priority over other activities of the same priority but not impact any *mandatory* activity. It should be noted that many key performance figures can be assessed only after a synthesis of several "important" activities. When such a synthesis is performed before the Commissioning Handover Review, it shall estimate how complete each contributing activity is, and may recommend to delay or revisit the subject in the future.

- *Beneficial* activities can be planned as background tasks with lower priority than mandatory and important activities. They may be postponed until after the Commissioning phase when contingencies affect higher priority activities. Anomaly correction for such activities shall not impact any *mandatory* or *important* activity.

[2] "Calibration and Validation" has entered common usage, and so this nomenclature has been adopted for this paper. However, since Metop planning addresses the generation of geophysical products in addition to radiances/brightness temperatures, retrieval should be understood also to fall under the umbrella of "Cal/Val".

- *Desirable* activities will not be carried out during the Commissioning Phase. However, should it happen that an opportunity arises and sufficient resources are available, such activities could be re-introduced in the schedule by the weekly planning meeting, at a low priority.

Cal/Val outputs include quantitative error estimates characterising the products, recommendations for changes to the auxiliary data employed for processing or to the processor itself, or for further (operational) monitoring/validation

Table 1: EURD product priorities (objective requirements)

Parameter	Accuracy Requirement (objective)	Product Priority
SCENE_RADIANCE	0.25 K for µ-wave and IR channels	1
ATMOSPHERIC_TEMPERATURE	*1.0 Troposphere, 1.0 Stratosphere*	1
ATMOSPHERIC_WATER_VAPOUR	5%	1
SURFACE_TEMPERATURE	0.4 K sea, 1.0 K land	3
FRACTIONAL_ CLOUD_COVER	5%	1
CLOUD_TOP_TEMPERATURE	1 K	1
CLOUD_TOP_PRESSURE	corresponding to < 200 m height error	2
TROPOPAUSE_HEIGHT	no requirement	3
CLW	0.01 mm	3
TOTAL_COLUMN_PREC_WATER	no requirement	2
Level 1 geolocation (all four instruments)	1 km along, 1.25 km across track localisation at nadir	1

Product processing is documented in the Product Generation Specifications and User Guides available from the EUMETSAT website (http://www.eumetsat.int). Validation involves the assessment and monitoring of product processing (thresholds, processing options, etc.), as well of the generated products themselves. The products will be checked for internal consistency, and also through comparisons. For the comparisons, EUMETSAT will focus on large, well-understood, operational datasets such as sondes, buoys, Numerical Weather Prediction, AMDAR (Aircraft Meteorological Data Reporting), other satellites, etc. Additional case studies will be carried out using specialised instrumentation such as spectrometers and radiometers deployed on the ground, aircraft, ships, stratospheric balloons, etc. A detailed listing of the Calibration and Validation activities currently foreseen can be found in the EPS Programme ATOVS Calibration and Validation Plan.

Cal/Val Facility

To support Cal/Val, a CVF and several tools have been developed. The initial configuration of the CVF includes nine operational PCs plus two development machines and primary & backup servers. The primary datastore can accommodate one month's Metop and NOAA data, and has access to the full EUMETSAT archive for retrieving additional archived data and reports. The PCs run IDL and ENVI in a Linux environment, but have been customised to suit the specific needs of the CVF.

An example CVF display is shown in Figure 1. The CVF has functionality for reading formatted datasets, generating standardised displays, performing anticipated investigations (radiative transfer, geolocation modelling, finding collocations, interpolations, etc.), and for carrying out automatic (scheduled) reporting. The design was optimised for flexibility, so as to be further programmable to adapt to future needs.

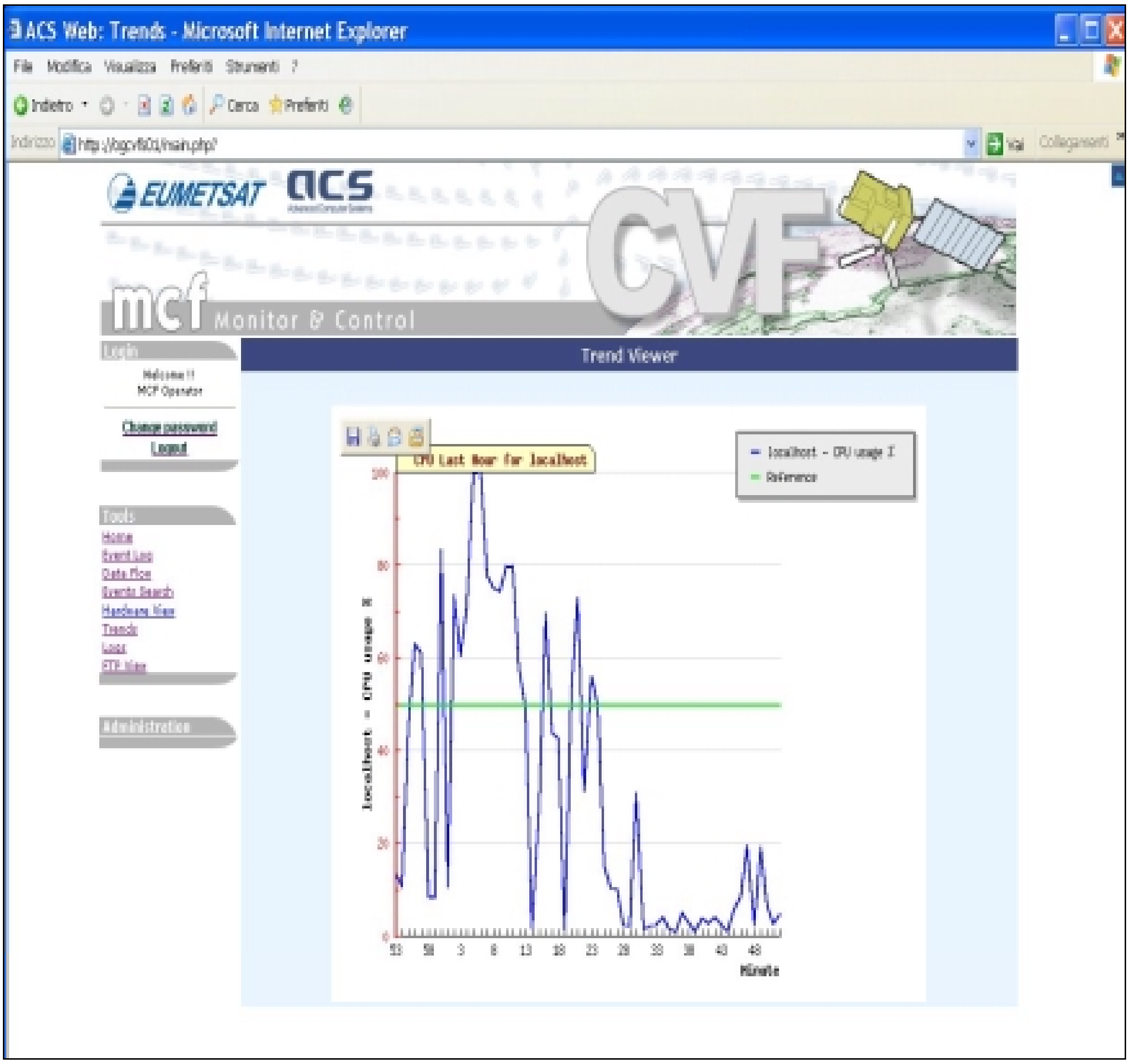

Fig. 1: CVF Example Display.

Cal/Val Tools

In addition to the CVF, extra tools have been created that can be used by the larger user community to support investigations of a broader interest. EUMETSAT is eager to hear from the users about any issues that they may discover when using the products. These tools have been approved for public release to the user community. Further details about tools can also be found at http://www.eumetsat.int/en/area4/eps/user_information.html.

The first tool is “EPSView”. It is Java-based and was designed to operate in a standalone mode. It can generate two-dimensional or geolocated images of product parameters. It provides for a tree-like drill-down into the full product, and the product can be inspected down to the bit level, if desired. An example display is given in Figure 2.

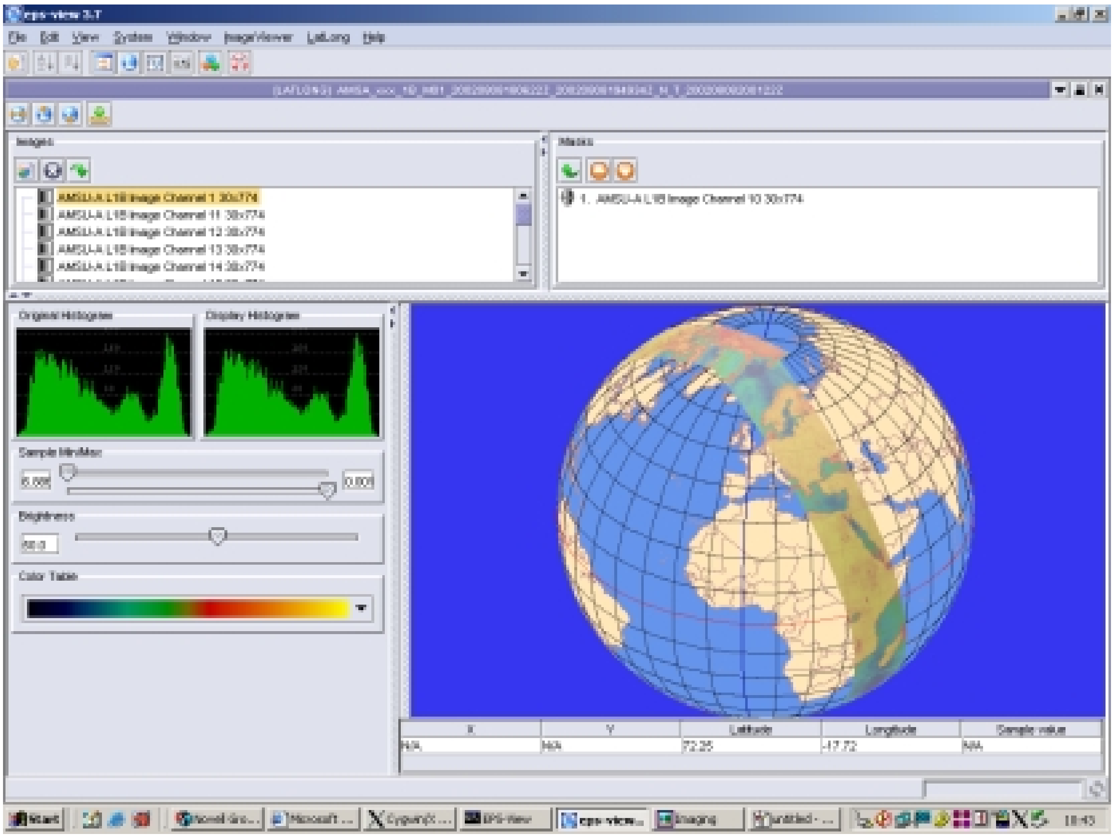

Fig. 2: EPSView Example Display

The next category of tools is IDL-based. These can also be run without a full IDL license using the (free) IDL virtual machine (http://www.rsinc.com/idlvm/index.asp), although in this environment do not offer significantly more functionality than the standalone EPSView tool. The "EPS Product Reader" can read the whole EPS product into memory and can also selectively read specific product fields and store pointers to these records/fields in the product object. It is employed by the "EPSMapper" and "EPSiPlotter" tools, and can also be run separately. EPSMapper can visualise data onto a map projection selected by the user. EPSiPlotter provides predefined product-specific visualisations for the product to permit more detailed analyses. These tools were designed for users familiar with IDL programming.

A final grouping of tools were developed for internal analyses but may also have some limited external applications. "noaa2eps" converts NOAA L1b products into EPS format products. If there is a need for additional EPS-format ATOVS products prior to launch this tool can be used to generate them. "Kai" can be used to combine Product Data Units (PDUs) into full products, e.g. in an Near Real Time (NRT) terminal. Finally, "Eugene" is a tool for creating, reformatting and modifying data files in various formats including EPS products, NOAA products and some text formats. It can be used as a command line product reader, or built as a library to access EPS products from C++ and Python.

Planned Cal/Val Activities

ESA will carry out an initial instrument checkout during the first six weeks after launch. Once completed, the Post-launch Cal/Val will then begin. An initial product checkout will be carried out against range limits, the instrument parameters and products will be visually inspected for visual anomalies, and tests will be conducted to investigate identified problem areas (based upon NOAA's prior experiences with these and related instruments). Trending will also begin of instrument characteristics and product parameters for monitoring purposes. NWP data will be employed for monitoring purposes. Outliers will be flagged for visual inspection on a daily basis to identify sudden changes in the products (or validation datasets).

A joint ESA/EUMETSAT Research Announcement of Opportunity (RAO http://www.eumetsat.int/en/area4/eps/epsmetop_rao.pdf) process is ongoing that will identify a number of external activities that can contribute to the scientific exploitation of EPS data and products. The RAO submissions could contribute to Cal/Val. Tentatively, a campaign will be carried out using extra radiosonde launches timed to coincide with Metop overpasses. The sites have not yet been selected, but preference will be given to those with nearby correlative measurements (radiometers, in-situ sampling, lidar, etc.).

Another key Cal/Val activity is to carry out regular comparisons against globally distributed measurements from operational networks (radiosondes, buoys and aircraft). Once it has itself been validated, Level 1 and Level 2 products from IASI will be employed for additional comparisons of radiances and geophysical products. Analyses will be also carried out using smaller numbers of high quality and high resolution datasets to improve confidence in the data. These will serve to validate the remaining products not measured by the operational networks, and also because the study of single matchups can reveal features that are not resolvable in bulk statistics

Two more exploratory areas may be investigated once the initial product behaviour has been established by the above activities. Firstly, recent work has highlighted the importance of information content when comparing disparate measurements, both due to noise/bias and also from the weighting functions associated with measurements made by different instruments (Rodgers and Connor 2002). A more rigorous analysis may therefore be applied as part of a lower-priority investigation to quantify uncertainties inherent in comparing retrieved quantities. Secondly, in-orbit experience with MOPITT (Deeter et al. 2002) has shown that it is sometimes possible to improve the knowledge of certain instrument spectral response characteristics via appropriate modelling. Given the importance of instrument spectral response functions to product processing and to the continuity of satellite datasets, this aspect may be investigated further.

Logic of Activities

Cal/Val activities have been sequenced as follows: Since AVHRR is critical to subsequent validation activities and as an input to ATOVS and IASI processing, it will be sequenced first. Its geolocation will be assessed, and then the cloud mask. Subsequently the geolocation and collocation of the ATOVS instruments will be assessed. After that the temperature and water vapour profiles will be evaluated against radiosondes, NWP and NOAA platform measurements. A number of other datasets (satellite-, land-, water- and air-based radiometers, lidar, in-situ sampling, etc.) may also be used on a lower priority basis. Dry runs of validation analyses will be carried out before launch for mandatory and important activities using

NOAA data. This will establish the necessary procedures, guarantee the appropriate tools are available and allow for faster generation of results post-launch.

Conclusions

Preparations for Calibration and Validation are under way at EUMETSAT. The EUMETSAT Cal/Val Facility has been procured to calibrate and validate EPS products. The Metop commissioning phase is scheduled to last the first six months following the launch. During this phase, the product validation will rely heavily on the use of large, well understood datasets, complemented by more detailed analyses where practical. Additional tools are available to the user community for independent analyses, and additional input has been solicited through the RAO mechanism.

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