

MIPAS CALIBRATION AND PROCESSOR VERIFICATION

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ABSTRACT

The Michelson Interferometer for Passive Atmospheric Sounding will be one of the atmospheric payload instrument on board ESA's polar orbiting ENVISAT. Sensing the Earth's limb emission in a wavelength range 4.15 ... 14.6 micrometers it will allow detection of a large number of middle atmospheric constituents of primary interest for various disciplines of atmospheric research. Besides generation of geolocated, fully calibrated limb radiance data (Level 1B products), abundance profiles of a set of primary target species, together with atmospheric pressure, temperature (Level 2 products) will be systematically processed and disseminated in near real time. Whereas the development of the essential on-ground algorithm components has been finalised work now focuses on the analysis of specific measurement scenarios that will be required in conjunction with the various planned post-launch verification and characterisation tasks. The work is carried out in a co-ordinated effort, involving expert teams already involved in earlier algorithm studies, and is supported through a number of specific projects initiated in the frame of the ENVISAT Announcement of Opportunity (AO). The primary tasks to be performed in the frame of the MIPAS CalVal project have been identified and an overall plan for their implementation has been established.

INTRODUCTION

As one of the atmospheric instruments on board ENVISAT MIPAS will routinely sense the Earth's limb emission in the mid-infrared and acquire radiance data in a total of 5 spectral bands ([1]). The mission concept foresees systematic processing of MIPAS scene and calibration measurements up to fully calibrated, geo-located limb radiance data (Level 1B) and vertical profiles of atmospheric pressure, temperature and volume-mixing-ratios of the primary target species O_3 , H_2O , CH_4 , N_2O , NO_2 and HNO_3 (Level 2). Prerequisites for a stable data acquisition and ground processing scenario are a number of calibration, characterisation and diagnostics activities that will support the operation of instrument and ground processor throughout the envisaged mission lifetime of four years. Moreover, the overall accuracies of geophysical parameters and associated information provided in the data products need to be evaluated and reported on, to allow full and correct interpretation by MIPAS users. This includes, in particular, the compilation of total error budgets, taking into account random and systematic contributions due to instrumental effects, characterisation uncertainties, in-flight calibration errors or modelling/approximation errors induced by the on-ground processing algorithms. Whenever appropriate ground processor functionalities and generated output parameters will be validated through intercomparisons with correlative information, provided through reference measurements or other, non-ENVISAT information sources.

This paper will discuss, after a brief review of primary MIPAS data products, envisaged activities related to initial in-flight calibration and characterisation. The strategy to verify critical components of the MIPAS Level 1B/2 processing stages as well as the role of the various expert teams supporting the MIPAS CalVal project will be outlined.

REVIEW OF MIPAS DATA PRODUCTS

During routine operation MIPAS data will be recorded on board ENVISAT and downlinked typically once per orbit, according to visibility of a receiving ground station. Each downlinked sequence will be converted into a so-called Level 0 product that will form the basis for all further processing. The Level 1B stage of the Instrument Processing Facility (IPF) performs the conversion of instrument raw data (scene, blackbody and deep space) and various auxiliary input data into fully calibrated, geo-located radiance spectra. A number of supplementary parameters are computed and included in the Level 1B product, to support the correct interpretation the further processing in the Level 2 component ([2]).

The Level 2 processing is based on the analysis of emission features of selected target gases from the Level 1B input data and is performed in two stages, (1) retrieval of p, T profiles and (2) sequential retrieval of VMR profiles for the six target species, using the pressure, temperature information retrieved in the first stage. Several auxiliary data are required that control, e.g., the extraction / pre-processing of the Level 1B input data or provide atmospheric state parameters as used by the iterative profile fit algorithm (see [3], [4]).

Tables 1 & 2 provide an overview of MIPAS data products and list some relevant performance parameters.

| Table 1. MIPAS Level 1B product summary | |
|--|--|
| PRODUCT | MIP_NL__1P |
| NAME | Geo-located, fully calibrated MIPAS limb emission spectra |
| DESCRIPTION | <p><i>Measurement data:</i> Spectrally and radiometrically calibrated limb emission spectra in the 685 - 2,410 wavenumber range 5 bands: A: 685-970 cm⁻¹, AB: 1,020-1,170 cm⁻¹, B: 1,215-1,500 cm⁻¹, C: 1,570-1,750 cm⁻¹, D: 1,820-2,410cm⁻¹</p> <p><i>Annotation data:</i> Geolocation information, product confidence data, processing parameters, NESR data, offset calibration data</p> |
| PRODUCT SIZE | approx. 310 Mbytes per orbit |
| COVERAGE | <p>Line-of-sight (LOS) tangent height range: 8 km ... 53 km (typ.)</p> <p>Pointing range (azimuth pointing relative to S/C velocity vector): 160⁰ - 190⁰ (rearward viewing) 75⁰ - 110⁰ (sideward viewing)</p> |
| ACQUISITION TIME | <p>duration of an interferometer stroke ('sweep'): ~ 4.45 s at high resolution (MPD = 20 cm) ~ 0.85 s at low resolution (MPD = 2 cm)</p> |
| GEOMETRIC RESOLUTION | <p>Instantaneous field of view (IFOV): 0.0523⁰ (elevation) * 0.523⁰ (azimuth)</p> <p>At LOS tangent point (effective): 3 km (vertical) * 30 km (horizontal) (rearward looking) 3 km (vertical) * 60 km (horizontal) (sideward looking)</p> <p>Horizontal displacement between subsequent elevation scan sequences (typ., rearward viewing): approx. 400 km</p> |
| SPECTRAL RESOLUTION | 0.031 cm ⁻¹ ... 0.035 cm ⁻¹ (for high resolution setting; MPD = 20 cm) |
| RADIOMETRIC ACCURACY | <p>685 - 1,500 cm⁻¹: 2 * NESR_T^a + 5 % [true source spectral radiance]</p> <p>1,570 - 2,410 cm⁻¹: 2 * NESR_T + X % of [true source spectral radiance], (X to be linearly interpolated between 2 at 1,570 cm⁻¹ and 3 at 2,410 cm⁻¹)</p> |
| AUXILIARY DATA | Instrument characterisation data, LOS calibration data, parameters controlling spectral calibration & instrument linesshape retrieval, orbit state vector & attitude information, others. |

a. Noise equivalent spectral radiance when the instrument is viewing a blackbody source at temperature T.

| Table 2. MIPAS Level 2 product summary sheet | |
|--|---|
| PRODUCT | MIP_NL_2P |
| NAME | Atmospheric pressure, temperature data, constituents profiles of primary MIPAS target species |
| DESCRIPTION | <p><i>Measurement data:</i> Geolocated, vertical profiles of p, T, O₃, H₂O, CH₄, N₂O, NO₂, HNO₃, tangent height correction data, profile variance/covariance data, concentration and column density profiles, fitted continuum absorption and radiometric offset parameters</p> <p><i>Annotation data:</i> Product confidence data, residual spectra, microwindow & occupation matrix data, evolution of state parameters during iterative fit procedure, processing parameters</p> |
| PRODUCT SIZE | approx. 8.2 Mbytes per orbit |
| COVERAGE | Global coverage, i.e. mapping of the Earth's upper Troposphere and Stratosphere at all latitudes and longitudes |
| GEOMETRIC RESOLUTION | Vertical resolution of p, T and VMR profiles: approx. 3 km Horizontal resolution of p, T and VMR profiles: approx. 400 km ... 500 km (along track) |
| AUXILIARY DATA | Spectroscopic data, pre-tabulated cross-sections, microwindows & occupation matrix data, validation thresholds, initial guess p, T and trace gas VMR profiles, a priori pointing information, processing setup / configuration parameters |

A description of the MIPAS data products, corresponding auxiliary input data and of the underlying processing algorithms is provided in *ENVISAT Simulated Products /MIPAS volume* (CD-ROM) [6].

COMMISSIONING PHASE CALIBRATION & VERIFICATION TASKS

Instrument & Level 1B related tasks

The initial period of MIPAS in-orbit operation will be dedicated to a number of specific checks and calibration measurements, in order to prepare the instrument for the routine exploitation. The envisaged activities can be grouped as follows:

- ***Switch-on and data acquisition phase (SODAP) tasks***
 - stabilisation of the instrument's thermal environment and initial 'switch on'
 - verification of the instrument's full functionality, commandability in various configurations and of the communication between instrument, satellite and on-ground facilities
- ***Initial instrument characterisation and optimisation of calibration scenario***
 - initial instrument related performance analysis (noise equivalent spectral radiance (NESR), instrument lineshape (ILS), line-of-sight (LOS) mispointing, ...)
 - drift analyses and optimisation of radiometric and spectral calibration cycles
 - re-computation and uplink of on-board settings & control tables
 - acquisition of initial calibration data for use in Level 1B processing
 - generation of a preliminary L1B data set for use in early Level 2 algorithm analyses
 - identification and correction of potential inconsistencies in the Level 0 to 1B processing stage
- ***full Level 1B related characterisation & validation***
 - update of in-flight characterisation data base and generation of full set of Level 1B auxiliary data
 - optimisation of specific Level 1B algorithm settings, to ensure correct performance and a stable output of the ground processor
 - initialisation of routine performance monitoring functions, i.e., definition of settings used on ground for routine instrument health checks and to detect potential degradations with respect to the initial performance
 - assessment of total Level 1B error budgets including instrument and algorithm induced inaccuracies.

Level 2 related tasks

In addition to the above listed tasks specific analyses are foreseen during commissioning phase that focus at the early verification of vital Level 2 algorithm components and auxiliary input data. These checks shall serve to identify inconsistencies in the L1B to L2 processing chain and to implement necessary corrections in affected algorithm components at a very early stage. This will ensure an improved performance of the Level 2 stage and the availability of a stable output data set for use in the different geophysical validations projects ([7]). These initial checks will be supported by dedicated characterisation measurements the results of which will be analysed according to pre-defined procedures. Use will be made of a suit of diagnostic tools specifically developed for this purpose.

The early Level 2 analysis work will focus on:

1. **instrument modelling:** check of validity of essential modelling/performance parameters, in particular:
 - ILS parameters, including spectral dependency
 - NESR levels, magnitude and spectral correlation
 - representation of field-of-view (FOV) pattern and FOV convolution model
 - modelling of LOS pointing perturbations (used as a priori input in p, T retrievals)
 - assumptions on residual radiometric and spectral calibration errors in Level 1B processing
2. **forward modelling:** checks of critical atmospheric sub-models and parameters, in particular:
 - volume-mixing-ratio (VMR) profiles of species interfering in selected retrieval spectral intervals ('microwindows')
 - initial guess profile data
 - impact of non-modelled high altitude line emissions (non-local thermodynamic equilibrium (NLTE) effects)
 - vertical and spectral correlations of non- or poorly modelled atmospheric continuum contributions
3. **pressure, temperature retrieval stage:** checks of retrieved pressure, temperature profiles through
 - intercomparisons with external data (e.g., geopotential, temperature fields from ECMWF analyses)
 - consistency check using information from the MIPAS line-of-sight (LOS) pointing system and the assumption of hydrostatic equilibrium in the observed target atmosphere
4. **VMR retrieval stage:** checks of retrieved VMR profiles through intercomparisons with external data, for a subset of target species (e.g., H₂O derived from ECMWF analyses)
5. **critical parameter tuning:** optimisation of performance critical settings, e.g.
 - parameters related to Level 1B data extraction/pre-processing
 - iteration feedback and threshold parameters
 - settings controlling the choice of retrieval unknowns.
6. **spectroscopic data base:** initial inspection of Level 1B radiances in retrieval microwindows, and of residual radiance spectra generated by the Level 2 algorithm, for completeness of selected line data and potential systematic errors
7. **overall processor performance:** analysis of specific Level 2 quality parameters, allowing to identify sources of excessive systematic errors in fit results, numerical instabilities, excessive CPU loads, etc.

Refer to [3], [4] for a more comprehensive discussion of the various sub-models.

TEAM COMPOSITION AND ASSIGNMENT OF TASKS

The MIPAS Cal/Val team is composed of several study groups the majority of which have been involved, as so-called Expert Support Laboratories (ESL's), in earlier work on instrument characterisation and algorithm development. A number of specific tasks will be carried out by expert groups involved in the CalVal activity through project proposals submitted in the frame of the ENVISAT Announcement of Opportunity (AO). **Table 3** list institutes/companies involved in the MIPAS CalVal work and summarises key tasks assigned to them.

Table 3. Overview of MIPAS calibration and algorithm verification activities

| Involved institutes / companies | Task | AO project |
|--|---|-----------------------|
| Instrument and Level 1B related work | | |
| ABB BOMEM Inc., ASTRIUM GmbH, ESA/ENVISAT project team | <ul style="list-style-type: none"> • characterisation & optimisation of instrument parameters (e.g., analog & digital signal processing) • characterisation of performance parameters (detector non-linearity, NESR levels, radiometric accuracy, drifts in radiometric gain / offset data, ILS shape & stability, spectral axis linearity, ...) • characterisation of systematic LOS mispointing (bias & orbit harmonics) • optimisation of settings for routine calibration measurements (spectral resolution, repeat cycles for deep space calibration, ...) • generation of template data for L1B validation functions • initialisation of long-term performance monitoring functions • routine generation and maintenance of L1B auxiliary data bases | - / - |
| FZ-IMK, DLR, IAA | <ul style="list-style-type: none"> • verification of NESR data reported in MIPAS L1B products • Verification of absence of noise correlation in calibrated MIPAS spectra • Verification of ILS parametrisation as implemented in IECF • Verification of ILS stability and characterisation of tangent altitude dependencies • spectral calibration analysis and characterisation of residual errors in L1B data • characterisation of spurious signals in deep space calibration measurements | AO#145 ("INFLIC") |
| DLR, FZ-IMK | <ul style="list-style-type: none"> • analysis of noise sources contributing to the overall NESR levels observed in L1B spectra • verification of detector non-linearity correction scheme implemented in MIPAS L1B algorithm by means of alternative analyses • assessment of L1B inaccuracies induced by erroneous characterisation parameters • verification of ILS retrieval algorithm by means of independent modelling • characterisation of systematic error sources due to simplified modelling in L1B / IECF algorithms | AO#652 ("IRAC") |
| Universities of Leicester, Canterbury and Hampton, LPM | validation of MIPAS Level 1B radiance data in selected spectral intervals (microwindows) by means of direct radiative transfer modelling | AO#357 ("CUTLSOM") |
| all teams | identification of potential errors in Level 1B algorithm and recommendations for enhancements of critical components and the auxiliary input data | |
| ABB BOMEM Inc., DJO GmbH | implementation & verification of Level 1B algorithm changes or auxiliary data enhancements as resulting from AO project and IECF activities | -/- |
| Level 2 related work | | |
| IROE-CNR, U. of Bologna, ISM-CNR, Universities of Oxford & Leicester, FZ-IMK, LPM | <ul style="list-style-type: none"> • in-depth analysis of specific L2 product parameters and identification of potential algorithm or auxiliary data induced errors • verification of spectroscopic line data base through inspection of residual radiance errors in L2 fit results • identification and quantification of systematic error sources in L2 results as induced, e.g., through <ul style="list-style-type: none"> - erroneous auxiliary data (e.g., spectroscopic line parameters, interfering gas concentrations) - incorrect atmospheric modelling (neglect of spatial gradients, deviations from hydrostatic equilibrium, ...) - incorrect instrument modelling (instantaneous field of view, ILS, LOS pointing fluctuations). | - / - |
| IROE-CNR, U. of Bologna, ISM-CNR, U. of Oxford, U. of Leicester, FZ-IMK, LPM, ASTRIUM GmbH, ESA/ENVISAT project team | <ul style="list-style-type: none"> • generation of intermediate L2 results for use by ESL / AO project teams • characterisation of the overall L2 algorithm performance • enhancement of L2 processing parameters through iterative tuning of algorithm sub-components • acquisition and re-formatting of L2 related auxiliary data bases generated external to the IECF • verification of overall consistency of auxiliary data bases, taking into account inter-dependencies • initialisation of long-term performance monitoring and validation functions | - / - |

| Table 3. Overview of MIPAS calibration and algorithm verification activities (... continued) | | |
|---|---|-------------------|
| Involved institutes / companies | Task | AO project |
| <i>Level 2 related work</i> | | |
| IAA, FZ-IMK, LPM | <ul style="list-style-type: none"> • verification of upper atmospheric CO₂ mixing ratios as used in routine L2 pressure, temperature retrievals • characterisation of Non Local Thermodynamic Equilibrium (NLTE) induced radiances in operational MIPAS retrieval microwindows • quantification of errors in L2 results due to neglect of NLTE effects for all MIPAS target species • recommendations for enhanced selection scheme for L2 retrieval microwindows and for the assessment of systematic errors in routine L2 retrievals | AO#304 |
| Universities of Leicester, Canterbury, Hampton, LPM | validation of MIPAS Level 1B radiance data in selected spectral intervals (microwindows) by means of direct radiative transfer modelling | AO#323 |
| all teams | <ul style="list-style-type: none"> • identification of potential error sources in the MIPAS IPF / Level 2 component • re-assessment of systematic error components and compilation of total L2 error budgets • consultancy during interpretation of MIPAS L2 key results in support of the correlative measurement and geophysical validation activities • recommendations with respect to enhancements of the overall Level 0 to 2 processing scheme and related auxiliary input data | |
| ASTRIUM GmbH, DJO GmbH | implementation & verification of Level 2 algorithm changes and updated auxiliary data. | - / - |

OVERALL TIMELINE

As outlined in the previous section, both, Level 1B and Level 2 related work will be carried out during the commissioning phase, whereas the L2 analyses will depend on the availability of a preliminary L1B data set. Pre-requisites for a successful completion of these tasks are the optimisation of instrument performance and the overall calibration scheme. The early commissioning phase activities will therefore focus on acquisition and analysis of dedicated characterisation measurements that allow to implement a stable measurement scenario and to generate the required ground processor output. It is envisaged to complete the optimisation of instrument settings (signal processing, LOS pointing correction tables, ..) and the - preliminary - characterisation of key parameters as required by the Level 2 stage (e.g., NESR, radiometric accuracy, ILS, spectral calibration) within the initial four months of ENVISAT's in orbit operation.

The actual Level 2 related analysis work will require the instrument to be operated in stable 'nominal' mode for specific periods (typically covering several orbits), with periodic limb measurements and radiometric calibration sequences. Data acquired during these intervals will be processed by the MIPAS PF and the generated Level 1B and Level 2 data products will be delivered to the involved expert teams.

The sequence of planned instrument and algorithm related characterisation and verification activities is illustrated in **Fig. 1**. Also indicated are the commissioning workshop and the validation review workshop, scheduled towards the end of commissioning phase and end of initial validation activities, respectively.

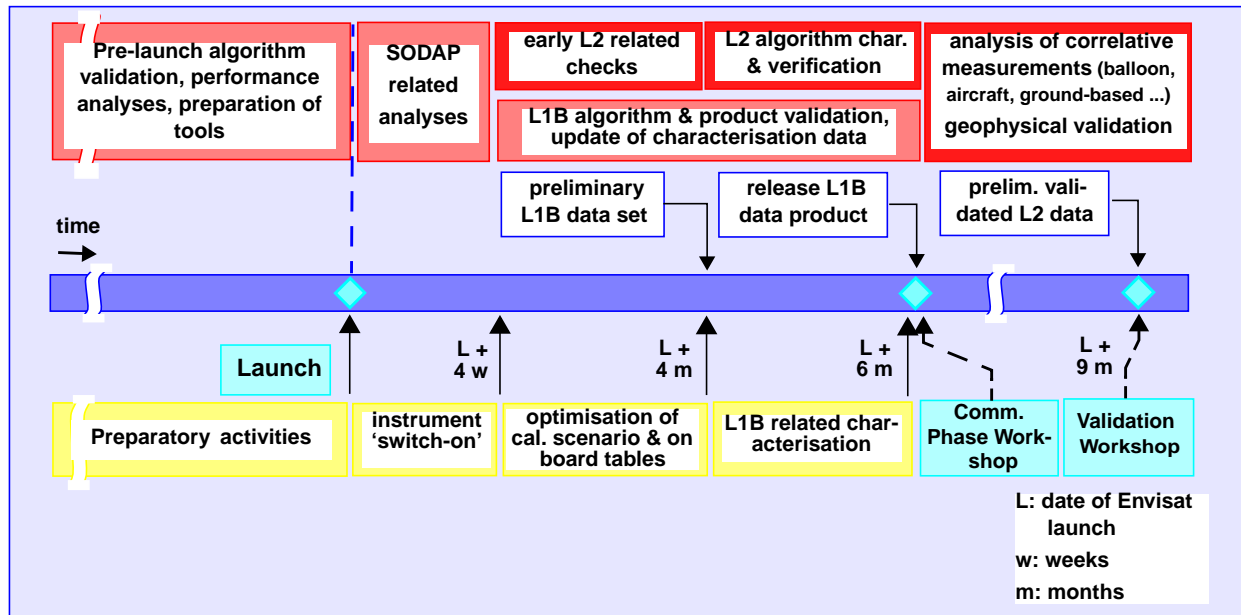


Fig. 1. Overall schedule of MIPAS Cal/Val activities.

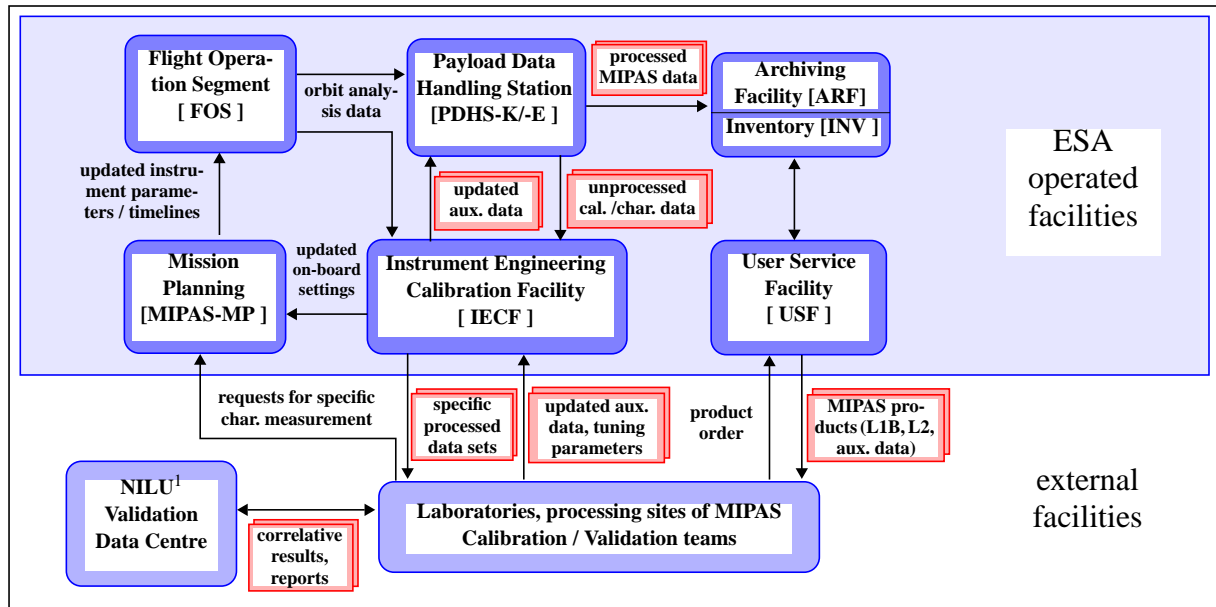
EARLY IN-FLIGHT INSTRUMENT OPERATION & DATA CIRCULATION

Prior to realisation of dedicated calibration and characterisation measurements various instrument settings and control parameters need to be computed and uploaded to the instrument. Once the instrument has been configured the actual command sequences to activate a particular measurement need to be uplinked, making use of previously optimised timeline parameters. Likewise, as soon as the actual measurement sequence has been acquired the instrument data received on ground need to be converted into a data product (e.g., a Level 1B file) and transferred to the site that will carry out the analysis. The implementation of such dedicated measurements requires a number of supporting on-ground facilities, in particular:

- **Mission Planning Tool [MIPAS-MP]**
Computation of on-board control parameters (e.g., pointing tables, timeline parameters, ...) for user requested scene / calibration measurements
- **Flight Operation Segment [FOS]**
Uplink of instrument control parameters, scheduling of command execution, analysis of orbit / attitude information
- **Paolod Data Handling Station Kiruna / ESRIN [PDHS-K / -E]**
Host of the MIPAS Processing Facility, will acquire instrument data and generate L1B & 2 data products
- **Archiving Facility (ARF) & Inventory (INV)**
Archiving of all MIPAS data products (L0, L1B, L2) and auxiliary data & inventory data base, will display contents of all archived ENVISAT data and supply details required for product ordering
- **User Service Facility [USF]**
Interface to ESA external data users, accepts product orders and provides processing status information to users
- **Instrument Engineering Calibration Facility [IECF]**
Processing of routine and dedicated calibration, characterisation measurements, performance monitoring, generation of L1B / L2 auxiliary input data used in the PDHS. During early in-orbit operation the IECF will generate specific results required by the CalVal groups for dedicated analysis work and, in turn, acquire data generated by them (e.g., updated auxiliary data bases or processor settings) for re-injection in the MIPAS processing chain.

In addition to these ESA operated facilities a dedicated validation data centre, the NILU data base, will be installed and maintained throughout the full duration of the ENVISAT CalVal activities. The NILU centre will host all correlative results generated for all ENVISAT instruments by the various calibration/validation teams and allow all involved groups to access data generated by the other teams.

An overview of the various ground facilities supporting the MIPAS CalVal activities, and of the primary data flows is given in **Fig. 2**.



¹ Norwegian Institute for Air Research

Fig. 2. Primary ground facilities and main data flows during early MIPAS in-flight operation and CalVal activities (simplified).

CONCLUSIONS

The MIPAS ground processing concept foresees routine generation, dissemination and archiving of raw instrument (Level 0) data and higher level (1B & 2) data products. A sound baseline has been established for both the Level 1B and 2 stages including the strategy for generating the auxiliary input data. Current work focuses on pre-launch validation of critical algorithm components and auxiliary data, and on the definition of dedicated calibration & characterisation measurements to be performed during the commissioning phase. The analysis and interpretation of acquired MIPAS data will be performed in the IECF as well as in various ESA external institutes involved in the ENVISAT CalVal project. The access to ENVISAT data and the implementation of updated L1B/L2 algorithm input data generated by CalVal groups will be facilitated through various centres within the ENVISAT ground segment. The circulation of results produced in the frame of the CalVal project will be supported by the NILU data centre, allowing all involved teams to access correlative information already at a very early stage during the instrument's in-orbit operation.

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