NWP SAF

AAPP Version 9 Product Specification

Version 1.0

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This documentation was developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), under the Cooperation Agreement dated 7 December 2016, between EUMETSAT and the Met Office, UK, by one or more partners within the NWP SAF. The partners in the NWP SAF are the Met Office, ECMWF, DWD and Météo France.

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1. INTRODUCTION

This document defines the specification for Version 9 of the ATOVS and AVHRR Pre-processing Package (AAPP), in accordance with the requirements of the NWP SAF. The Product Specification describes the deliverable from the point of view of the user.

It concentrates on those aspects of AAPP that are new in version 9 – for more details on the specification of previous versions of AAPP, see RD-9, RD-10 and RD-11.

1.1 Reference documents

[RD-1] NWPSAF-MF-UD-001, AAPP Documentation Scientific Description
[RD-2] NWPSAF-MF-UD-002, AAPP Documentation Software Description
[RD-3] NWPSAF-MF-UD-003, AAPP Documentation Data Formats
[RD-4] NWPSAF-MO-UD-004, AAPP Overview
[RD-5] NWPSAF-MO-UD-005, AAPP Installation Guide
[RD-6] NWPSAF-MO-UD-036, AAPP User Guide
[RD-7] NWPSAF-MF-UD-003, OPS-LRS User Manual
[RD-8] NWPSAF-MO-UD-027, Annex to AAPP scientific documentation: Pre-processing of ATMS and CrIS
[RD-9] NWPSAF-MF-UD-011, VIIRS-CrIS mapping
[RD-10] NWPSAF-MO-DS-010, AAPP Version 6 Product Specification
[RD-11] NWPSAF-MO-DS-014, AAPP Version 7 Product Specification
[RD-12] NWPSAF-MO-DS-033, AAPP Version 8 Product Specification
[RD-13] NWP SAF Proposal for the Third Continuous Development and Operations Phase (CDOP-3) March 2017-February 2022
[RD-14] NWP SAF Proposal for the Fourth Continuous Development and Operations Phase (CDOP-4) March 2022-February 2027
[RD-15] NWPSAF-MO-DS-033, EPS-SG pre-processing in AAPP and MWIPP, available from https://nwp-saf.eumetsat.int/site/software/aapp/future-plans/

2. USER REQUIREMENTS

2.1 General considerations

User requirements for AAPP are gathered by several methods:

- The NWP SAF planning process, specifically the CDOP-3 and CDOP-4 proposals which are agreed by the Steering Group and approved by EUMETSAT Council
- Discussions at conferences, particularly the Products and Software Working Group at International TOVS Study Conferences
- Discussions at meetings such as the DBNet Coordination Group
- Feedback from users via the NWP SAF Helpdesk
- Feedback from users in connection with NWP collaboration projects
- Surveys

Additionally, requirements can arise due to external constraints, e.g.

- Satellite launches, launch delays or termination of satellite missions
- Support for new software compilers, or cessation of support for old compilers
- Changes in external packages on which AAPP relies
- Availability of ancillary data

2.2 Input from the CDOP-3 and CDOP-4 proposals (RD-13 and RD-14)

RD-13 makes the following statements about AAPP future developments relevant to v9:

1. AAPP v9 is to include Metop-SG capability.
2. First release will be tested with simulated data; updates to follow as needed based on real data.
3. Prepare preprocessing support for the sounders on Metop-SG-A1, i.e. Microwave Sounder (MWS) and Infrared Atmospheric Sounding Interferometer - New Generation (IASI-NG). This will include ingest of level 1 files created by external DB software, re-mapping and filtering capability and BUFR encode/decode capability.
4. Implement the IASI-NG level1 processing, successor of the OPS-LRS. Port the EUMETSAT original software to the AAPP environment
5. Port EUMETSAT software for MWS and METImage to the AAPP environment
6. Plan and implement the cloud mask for Metop-SG-A1. It is intended that direct broadcast applications that require a cloud mask will use the cloud mask provided by NWC-SAF/PPS.The NWP SAF will ensure that level 1 IASI-NG processing for direct broadcast is compatible with the PPS cloud mask output.

It has since been clarified, and confirmed in RD-14, that direct broadcast level 1 processing will be carried out by dedicated software to be procured by EUMETSAT, i.e. *external to AAPP*. This software will be delivered in a new NWP SAF deliverable *EPSSGL1*. Thus bullet points 4, 5 and 6 in the list above are no longer applicable to the AAPP deliverable. Note that the PPS cloud mask will be an input to the IASI processing in EPSSGL1, it will not be an input to AAPP.

The main new function of AAPP v9, as far as Metop-SG is concerned, will therefore be the pre-processing of MWS and IASI-NG level 1 files. There is also a requirement to maintain existing capabilities.

2.3 Input from ITSC-23 (June 2021)

In preparation for ITSC-23, document RD-14 was prepared outlining a design strategy for the NWP SAF software to be prepared for EPS-SG and MTG. The document explains foreseen requirements for AAPP:

- To support the standard EUMETSAT level 1 products in netCDF format, applicable to the local (direct broadcast) mission
- To support EUMETSAT level 1 products that will be delivered in BUFR (applicable to global and regional mission dissemination)
- Requirement to perform spatial filtering and thinning for MWS, to improve its usefulness for NWP (as is done for ATMS)
- Requirement to generate standalone microwave scattering tests for MWS, updated versions of those originally devised for AMSU/MHS. A 229 GHz scattering test is proposed.
- Support Principal Components processing for IASI-NG; generate reconstructed radiances; spatial thinning; change the spectral resolution (i.e. convert IASI-NG to the resolution of IASI)
- Generate BUFR outputs that are optimised for NWP use.

These aspects (and others related to the other satellites) were presented in a talk[1] and user feedback was requested. The Products and Software Working Group (PSWG) was also informed of these developments.

Note that the Metop-SG processing modules are foreseen as separate from the "core AAPP", and may be supplied as a separate tar file (as is the case for OSP-LRS). But this is a matter for design rather than requirement.

To date, no specific feedback has been received from users. The PSWG did, however, give two recommendations related to the software packaging:

> **New Recommendation PSWG-2: Software providers should, where possible, offer their software with a choice of either pre-built binaries or source code.**
>
> **New Recommendation PSWG-3 to Software Providers: For software that will be built from source by the user, software providers should list recommended versions of required external (COTS) libraries.**

2.4 Met Office requirements

Met Office requirements for EPS-SG data reception and processing are given in SA Technical Memo number 104, dated 31st December 2019 (internal report). The pre-processing requirements for the sounders can be summarised as follows:

- Requirement to ingest netCDF and BUFR, depending on the origin of the data (global / regional / local)
- For global model, spatial filtering of MWS to approximately 40km is required, with corresponding noise reduction (as implemented for ATMS)
- For UK model, the MWS data will be used at full resolution (as for MHS)
- The processed data are to be stored in BUFR
- For IASI-NG, the day-1 requirement is to degrade the data to IASI-like spectral resolution (i.e. 0.25 cm^{-1} sampling) and to process as currently done for IASI.
- The software should be flexible enough to carry out this spectral manipulation for both full-spectrum input datasets and for PC-compressed datasets
- Store IASI-NG at full resolution for a limited region (near UK), and at reduced resolution globally (1 in 4 spots)
- The document suggests that mapping of MWS to IASI-NG could be needed. Subsequent discussion clarified that this is not a requirement for assimilation, though mapped MWS could be helpful in the IASI-NG thinning process.

There is no Met Office requirement for METimage data to be included in the MWS or IASI-NG products. METimage imagery will be generated for forecaster use, but that is outside the scope of AAPP.

2.5 DBNet requirements

[1] http://cimss.ssec.wisc.edu/itwg/itsc/itsc23/presentations/oral.3.01.atkinson.pdf

DBNet requirements are reviewed regularly at meetings of the DBNet Coordination Group[2]. Extension of DBNet services to support MWS and IASI-NG are planned. Specifically:

- EUMETSAT will be introducing their regional service for Metop-SG, for core stations, that is independent of AAPP – it will use the global processing infrastructure.
- All other DBNet stations will make use of the EPSSGL1 processor for MWS and IASI-NG, with the outputs feeding into AAPP for BUFR encoding.
- It is not yet decided whether DBNet stations will run the PPS cloud mask operationally, to feed into IASI L1 processor. But this does not directly affect the AAPP processing.

The main requirement for AAPP as far as DBNet is concerned is that the BUFR products generated from AAPP are consistent with the corresponding global product, in format and quality. The WMO “Guide to DBNet" states that

> *Global and local product processing shall be harmonized in that brightness temperature products derived from both paths agree within tolerances that are not greater than a few tenths (the goal is 10%) of the respective performance requirements for bias error at a reference brightness temperature.*

2.6 Requirements for inputs to retrieval packages

AAPP outputs are sometimes used as input to level 2 retrieval packages. The requirements are listed below. No significant changes have been noted in this area.

- IAPP[3] requires HIRS level 1d in AAPP format with mapped AMSU and MHS. AVHRR is not required.
- MIRS[4] requires AMSU and MHS level 1b in AAPP format (NOAA and Metop satellites).
- UW CrIS, AIRS and IASI Hyperspectral Retrieval Software (HSRTV)[5] requires IASI PFS format.
- CSPP_HEAP (NUCAPS)[6] software requires IASI PFS format and AMSU/MHS level 1b in AAPP format (Metop satellites)

We would expect that some of the above packages will be adapted for EPS-SG use, but no details have been announced.

2.7 Requirements for processing of historical data

During CDOP-2 and CDOP-3, AAPP was enhanced to support ingest of pre-NOAA-K level 1b data from NOAA CLASS (HIRS and MSU). No new requirements have been noted in this area. Existing functionality should be maintained.

AAPP can also be used to process archived level 0 data from Metop satellites. Again, no new requirements have been noted, other than the need to maintain the software and ancillary data.

2.8 Summary of user requirements for AAPP v9

[2] https://community.wmo.int/activity-areas/wmo-space-programme-wsp/dbnet
[3] http://cimss.ssec.wisc.edu/cspp/iapp_v1.1.shtml
[4] https://www.star.nesdis.noaa.gov/mirs/
[5] http://cimss.ssec.wisc.edu/cspp/uwhsrtv_edr_v2.0.shtml
[6] http://cimss.ssec.wisc.edu/cspp/heap_v2.0.shtml

Support for EPS-SG

AAPP will be used to process data for the two sounder instruments on the Metop-SG-A satellite series: MWS and IASI-NG

Unlike Metop first generation, AAPP will not be required to carry out instrument calibration and navigation for direct broadcast applications. That function will be done in dedicated level 1 processors (EPSSGL1). Instead, AAPP will need to ingest

- The level 1 data files that are created by the level 1 processors (netCDF format)
- Global and regional level 1 data, distributed by EUMETSAT (BUFR format).

Pre-processing should include:

- Spatial filtering for MWS
- Microwave scattering tests for MWS, including a 229 GHz scattering test
- Support for Principal Components for IASI-NG; generation of reconstructed radiances; spatial thinning; ability to change the spectral resolution (i.e. convert IASI-NG to the resolution of IASI)
- Generate BUFR outputs that are suitable for NWP use

Other supported satellites

Continued maintenance is required to support level 1 processing of data from Metop-B, Metop-C and the legacy NOAA satellites (NOAA-15/18/19)

Continued maintenance is required to support ingest and pre-processing of NOAA-20, Suomi-NPP and FY-3D data, for which the level 1 processing is carried out by external software (i.e. CSPP SDR[7] and FY3DL1PP).

FY-3E data (MWTS2, MWHS2, HIRAS-2) will start to be used operationally, and routine extension of AAPP will be needed to support these instruments.

JPSS-2 and follow-on FY-3 satellites are expected to be launched before or during the lifetime of AAPP v9, and will need support in the same way as currently done for JPSS-1 and FY-3D.

Package delivery

Offer AAPP v9 package as (i) source code and (ii) executables built on a reference platform.

In the case of source code, recommended library versions should be given. In the case of executables, the necessary dynamic libraries should be included.

3. FUNCTIONALITY, INPUTS AND OUTPUTS

AAPP v9 will provide the functionality of previous versions of AAPP. For NOAA and MetOp satellites it will be backward compatible in terms of user operation, input data and output data – as described in RD-1, RD-2, RD-3 and RD-4.

AAPP v9 will provide the following main functions. Features changed in v9 are shown in *blue italic*.

[7] https://cimss.ssec.wisc.edu/cspp/

Raw data processing

- Ingest raw HRPT data files from the NOAA POES satellites. Input either big-endian or little-endian.
- Ingest "level 0" files from the Metop satellites.
- Calibrate and Earth locate the ATOVS and AVHRR instrument data (or TOVS and AVHRR data in the case of pre-NOAA-15 satellites[8]). The ATOVS instruments comprise AMSU-A, AMSU-B (or MHS) and HIRS. The TOVS instruments comprise MSU and HIRS.
- Level 1 processing for IASI (via the optional package OPS-LRS)

Ingest of externally-generated level 1 data (non-BUFR)

- Ingest level 1b AMSU, MHS, HIRS and AVHRR files from NOAA (e.g. from the CLASS archive). Includes handling of historical data.
- Ingest Sensor Data Records (SDRs) in hdf5 format from ATMS, CrIS and VIIRS on Suomi-NPP and JPSS satellites. AAPP will not process raw data for these satellites; external software packages are available.
- Ingest SDRs in hdf5 format from the sounders on FengYun-3 satellite series. AAPP will not process raw data for these satellites; external software packages are available.
- For AVHRR, convert between level 1b "PFS format" and AAPP format.
- *Ingest level 1 MWS and IASI-NG data in netCDF format. This includes output from the EPS-SG direct broadcast software (EPSSGL1).*

BUFR input and output

- Ingest level 1c BUFR files that comply with WMO sequences, for AMSU, MHS, HIRS, IASI, ATMS, CrIS, MWHS, MWHS-2, MWTS, MWTS-2, IRAS and MWRI.
- Generate level 1c BUFR files that comply with WMO sequences, for AMSU, MHS, HIRS, IASI, ATMS, CrIS, MWHS, MWHS-2, MWTS, MWTS-2, IRAS and MWRI.
- Generate other BUFR formats, e.g. level 1d used at Met Office.
- Interfaces to BUFRDC *and ecCodes*.
- *Ingest level 1 MWS and IASI-NG data in BUFR format*
- *Convert level 1 MWS and IASI-NG data from netCDF to BUFR that is compatible with EUMETSAT products*

Sounder preprocessing

- For ATOVS, convert level 1b to level 1c (radiance) and level 1d (instruments mapped to a common grid).
- Pre-processing of IASI: map AMSU/MHS to IASI; spectral thinning (including Principal Components); spatial thinning.
- Pre-processing of ATMS and CrIS: map ATMS to CrIS; spatial filtering of ATMS; spectral and spatial thinning of CrIS.
- Pre-processing of FY-3 sounders: map MWHS-2 to MWTS-2.
- Generate microwave scattering indexes for AMSU, MHS *and MWS*
- *Pre-processing of MWS and IASI-NG: spatial filtering of MWS; map MWS to IASI-NG; spectral and spatial thinning of IASI-NG.*
- *Option to degrade IASI-NG data to IASI-like spectral resolution (i.e. 0.25 cm^{-1} sampling)*

Cloud mask and imager analysis

- MAIA cloud mask (MAIA4) supporting AVHRR and VIIRS, with provision to download ancillary forecast files automatically from the internet.

[8] Calibration is provided for NOAA-9 onwards.

- VIIRS to CrIS mapping [RD-9]
- AVHRR mapping to HIRS grid. Optionally, the cloud information from MAIA4 may be mapped to the HIRS grid.
- Imager clusters generation for AVHRR-IASI (part of OPS-LRS) and VIIRS-CrIS [RD-9].

AAPP outputs

Different user applications require different output formats. Supported formats include:

- AAPP binary level 1b, 1c and 1d (details in RD-3)
- hdf5 versions of the level 1b, 1c and 1d formats, where the “header record” is used to set hdf5 attributes, and the “data records” are used to set hdf5 data arrays.
- Other hdf5 outputs (including MAIA4 products)
- BUFR
- PFS format (Metop-specific) for IASI level 1c and AVHRR level 1b
- *netCDF for IASI-NG and MWS. Outputs may be appended to the input files where applicable.*

Note that several satellite launches are planned during the lifetime of AAPP v9 (e.g. JPSS-2, FY-3F). Extension of AAPP to handle the data will be done through the normal AAPP update process and will not necessarily correspond with a new major release.

4. SOFTWARE PROVISION AND BUILD

AAPP will normally be supplied in the form of source code, downloadable from the NWPSAF web site (after user registration). The user will be expected to build the package, according to the instructions provided in the AAPP Installation Guide. The normal sequence is:

1. Build external any necessary external libraries, if not already installed (e.g. HDF5, netCDF, ecCodes). Guidance will be given, including recommended version numbers.
2. Configure AAPP (specifying fortran compilers, etc.)
3. Make
4. If required, build OPS-LRS, according to the instructions in the OPS-LRS user Manual (RD-7)

Data files and test cases will need to be downloaded from the NWPSAF web site.

Orbital elements (if required) will need to be downloaded from external sources. Guidance is given in the AAPP User Guide (RD-6).

For AAPP v9, the option will also be provided for users to receive AAPP executables, built in a reference Linux system (e.g. Red Hat 7) and packaged with the necessary dynamic libraries.

5. SYSTEM REQUIREMENTS

5.1 Language

As in previous versions of AAPP, the code will be written in a mixture of FORTRAN77, Fortran 90, C and C++. The code will be capable of compilation on a range of Fortran 90, C and C++ compilers.

Shell scripts will be based on the Korn shell, Bash shell, Perl and (optionally) Python.

5.2 Operating system and hardware

AAPP is required to run on commonly-available UNIX or Linux platforms. 64-bit systems are preferred. Based on past experience it is expected to run on 32-bit systems also, but the NWP SAF no longer has access to 32-bit test facilities.

Disk space requirements: the AAPP/OPS-LRS software and data files occupy about 9GB of disk space (or 4GB if you don't need to run MAIA4, the VIIRS cloud mask).

Memory requirements: there are no special requirements to run the core parts of AAPP (e.g. ATOVS/AVHRR processing). IASI processing requires at least 2GB of memory, but runs faster on systems with more memory, because more threads can be used. At least 6GB is recommended.

The core of OPS-LRS is parallelized using POSIX threads. Therefore OPS-LRS requires a platform where POSIX threads are implemented.

5.3 Performance

Examples of run times, for the various components of AAPP, will be provided in the Test Log. There are no specific requirements, as run-times depend on processor speed, memory, etc.

In some cases, the run-time is determined by the performance of external software (e.g. ecCodes).

5.4 Interface requirements

Where external libraries are required, AAPP v8 may rely only on free software libraries. These libraries will either be packaged together with the relevant sections of AAPP (e.g. xerces and fftw are packaged together with OPS-LRS) or the user will be given instructions on how to download them from a third party (e.g. ECMWF).

6. DOCUMENTATION

The AAPP scientific and technical documentation (RD-1 to 6) will be updated to include descriptions of the new capabilities.

On release of AAPP v9, the documents will be made available on the main AAPP web pages.

7. LIST OF REQUIREMENTS

This section details specific requirements to be addressed in the AAPP v9 Test Plan.

7.1 The Release Note accompanying the package shall list the contents of the package and how to unpack the software.

7.2 AAPP v9 shall be successfully built from source, following the instructions in the Installation Guide. Where the user requires, it shall be possible to link external libraries to AAPP, including BUFRDC, ecCodes, HDF5 and netCDF.

7.3 The software shall compile and run on a Unix platforms. Linux PC is mandatory, macOS is desirable.

7.4 Developers will also aim to provide AAPP v9 as executables, built on a reference Linux system, with dynamic libraries. This is not a mandatory requirement but has been recommended by users.

7.5 NOAA and MetOp direct readout test cases for ATOVS, AVHRR and IASI shall run to completion, and shall have no unexpected differences between v8 and v9 in the accuracy or coverage of the output products. The Metop test case is to include OPS-LRS. Tolerances will be defined more fully in the Test Plan.

7.6 Test cases for MetOp BUFR and IASI principal components shall run to completion, and shall have no unexpected differences between v8 and v9 in the accuracy or coverage of the output products.

7.7 A test case for MAIA4 shall run to completion, and shall have no unexpected differences between v8 and v9.

7.8 A test case for the imager clusters generation shall run to completion, and shall have no unexpected differences between v8 and v9.

7.9 BUFR tests shall run to completion, and shall have no unexpected differences between v8 and v9. These tests involve both BUFR decoding and encoding.

7.10 AAPP shall be capable of outputting the formats specified in section 2.6, for interfacing to level 2 retrieval packages. Testing of the retrieval packages themselves is outside the scope of the AAPP specification.

7.11 Test cases shall be created for MWS and IASI-NG, exercising the functionality of section 2.8. These may be initially based on pre-launch simulated data and will be defined more fully in the Test Plan. The software shall be capable of processing both data from the level 1 processors (EPSSGL1) and data from EUMETSAT’s ground segment.

7.12 On release, appropriate test cases shall be made available to users via the NWP SAF web pages.