

AAPP developments and experiences with processing METOP data

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Introduction

The ATOVS and AVHRR Pre-processing Package (AAPP) is a software package maintained by the EUMETSAT Satellite Application Facility for Numerical Weather Prediction (NWP SAF). The host institute for the NWP SAF is the Met Office, with partners ECMWF, KNMI and Météo-France (see <http://www.nwpsaf.org>).

AAPP version 6.1 and the IASI Level 1 processor OPS-LRS were released to users in October 2006, shortly before the launch of MetOp-A. Since then a number of updates have been issued, as the software has been refined in the light of post-launch MetOp data. Please see the NWP SAF web site for details of the current release.

This paper describes the new features to be found in version 6 and its updates. It then describes some recent developments in an application of AAPP – the Regional ATOVS Retransmission Services (RARS). Finally we consider the extension of AAPP to new satellites such as NPP and NPOESS.

AAPP Capabilities

AAPP can be used to perform level 1 processing on the following types of polar-orbiter data:

- Locally-received direct readout data (HRPT or AHRPT)
- Regional data, e.g. EARS and RARS. Normally received BUFR-encoded at level 1c, but can be level 1a or 1b.
- Global data, e.g. from NESDIS or EUMETSAT

Of the current generation of polar-orbiting satellites, the following are supported in AAPP: NOAA-15, NOAA-16, NOAA-17, NOAA-18, MetOp-A and FY-1D. The supported instruments are as follows: AMSU, MHS, HIRS, IASI, AVHRR and the FY-1D imager MVISR.

For a series of block diagrams illustrating the AAPP processing flow, see Atkinson et. al. (2006).

Processing of MetOp data

During the first half of 2007 AAPP was used operationally at a number of centres (including Met Office and Météo-France) to process the MetOp direct-readout data. This included the processing of IASI using the OPS-LRS package. A detailed comparison study of IASI local processing versus global processing was performed by Marguinaud et. al. (2007); the study concluded that although there are some small differences in the radiances, the reasons for the differences are well understood and they are not expected to be significant for Numerical Weather Prediction (NWP).

Unfortunately the primary AHRPT transmitter on MetOp-A failed on 4th July 2007 and to date there has been no activation of the secondary transmitter. Nevertheless users of OPS-LRS are encouraged to keep their software up to date in order to ensure local-global consistency should it be possible to activate the secondary transmitter in the future.

Despite the lack of AHRPT, imagery from AVHRR is still available to users via the EPS global data service, with a timeliness of approximately 1.5 to 2 hours. A tool has been added to AAPP that converts the EPS format data into the AAPP level 1b format.

Processing of FY-1D imager data

A new feature in AAPP update 6.6 (released Feb 2008) has been the ability to process direct readout data from FY-1D. AAPP takes the five AVHRR-like channels of the MVISR imager, performs calibration and geolocation tasks and creates standard AAPP-format level 1b files. MVISR has ten channels: channels 1-5 are similar to AVHRR while channels 6-10 are additional visible/near IR channels for ocean colour, water vapour and ice/snow characterisation. Centre frequencies are listed in Liu et. al. (1999).

The instrument does have some problems (channel 3 is noisy), and the quality of the calibration and navigation is not as good as it is on NOAA satellites. But the imagery is still of useful quality. For a detailed discussion of FY-1D issues, see Levin et. al., 2005.

There are no plans at present to extend AAPP to process data from the FY-3 series – which includes infrared and microwave sounders. Instead, it is hoped that the China Meteorological Administration will provide a suitable level 1 processing package. FY-3A was launched on 27 May 2008.

Development of IASI Principal Components

As part of *atovpp*, the user has a number of options which may be used to reduce the volume of the IASI level 1 data. These include:

- Channel selection – a set of 314 channels is provided (Collard, 2007) or the user can define his own channel selection
- Spatial thinning – choose one detector out of the four, either a fixed detector or one chosen dynamically based on the variability of the mapped AVHRR pixels
- Principal components (PCs) – the eigenvectors are supplied in a data file and the user can define how many PCs to use

In AAPP update 6.6 the handling of the PCs was enhanced to be compatible with the software package developed at ECMWF for the generation of the eigenvectors from a training set of spectra. This package is to be released as an NWP SAF deliverable.

The basic steps in the generation of the eigenvectors from a training set of spectra are:

1. Noise-normalise each radiance spectrum and subtract the mean. Call the result \mathbf{y} .
2. Form the covariance matrix from a large number (n) of training spectra:

$$\mathbf{Y}\mathbf{Y}^T = \sum (\mathbf{y}\mathbf{y}^T)$$

3. Generate the eigenvectors, \mathbf{U} , using PCA:

$$\mathbf{Y}\mathbf{Y}^T / n = \mathbf{U}\mathbf{w}\mathbf{U}^T$$

AAPP then reads in the eigenvectors and computes the scores, \mathbf{c} , for the near-real-time spectra, \mathbf{y}'

$$\mathbf{c} = \mathbf{U}^T \mathbf{y}'$$

The scores are stored in the IASI level 1d file.

AAPP update 6.6 includes a set of eigenvectors generated from 6 months of IASI data from July to December 2007. A set of 15736 spectra was used, generated by taking one day in every five, one 3-minute granule in every four, and between one and six spectra per granule depending on latitude – in order to avoid giving undue weight to polar spectra.

By default, AAPP de-apodises the spectra before computing the PC scores in order to ensure a diagonal noise covariance. But users can use apodised (level 1C) spectra if they prefer (e.g. time-critical applications).

Examination of the eigenvalues showed that the optimum number of PCs for the global training set is about 125-150: see Figure 1.

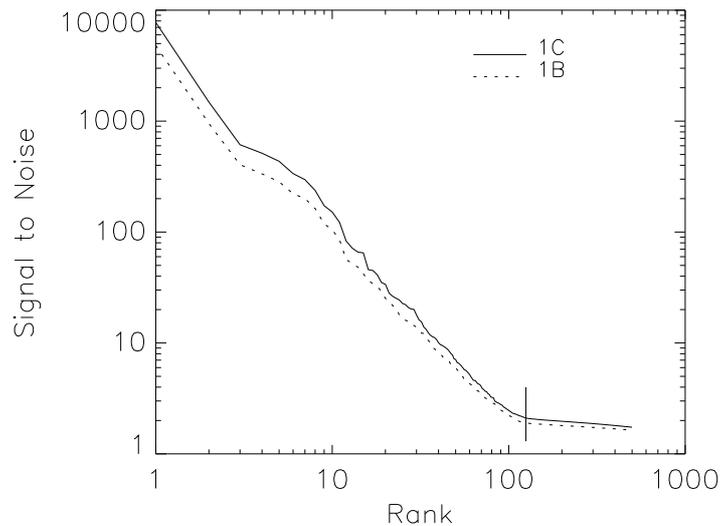


Figure 1: Square root of the eigenvalues for training dataset. The vertical line is at rank 125 and is where noise starts to dominate. The analysis has been carried out for both apodised spectra (1C) and de-apodised (1B), with similar results.

Since the instrument noise is roughly evenly distributed amongst the PCs, by retaining 150 PCs rather than all 8461 one would expect that the noise in the reconstructed radiances would be reduced by a factor $\sqrt{(150/8461)} = 0.13$. In practice this is probably rather optimistic, but simulations suggest that 0.18 should be achievable. For NWP this noise reduction would be expected to have the most impact for the stratospheric and upper tropospheric temperature sounding channels around $650\text{-}750\text{ cm}^{-1}$, where instrument noise is high relative to background error ($\sim 0.3\text{K}$). The instrument noise, together with the AAPP default channel selection, is shown in Figure 2.

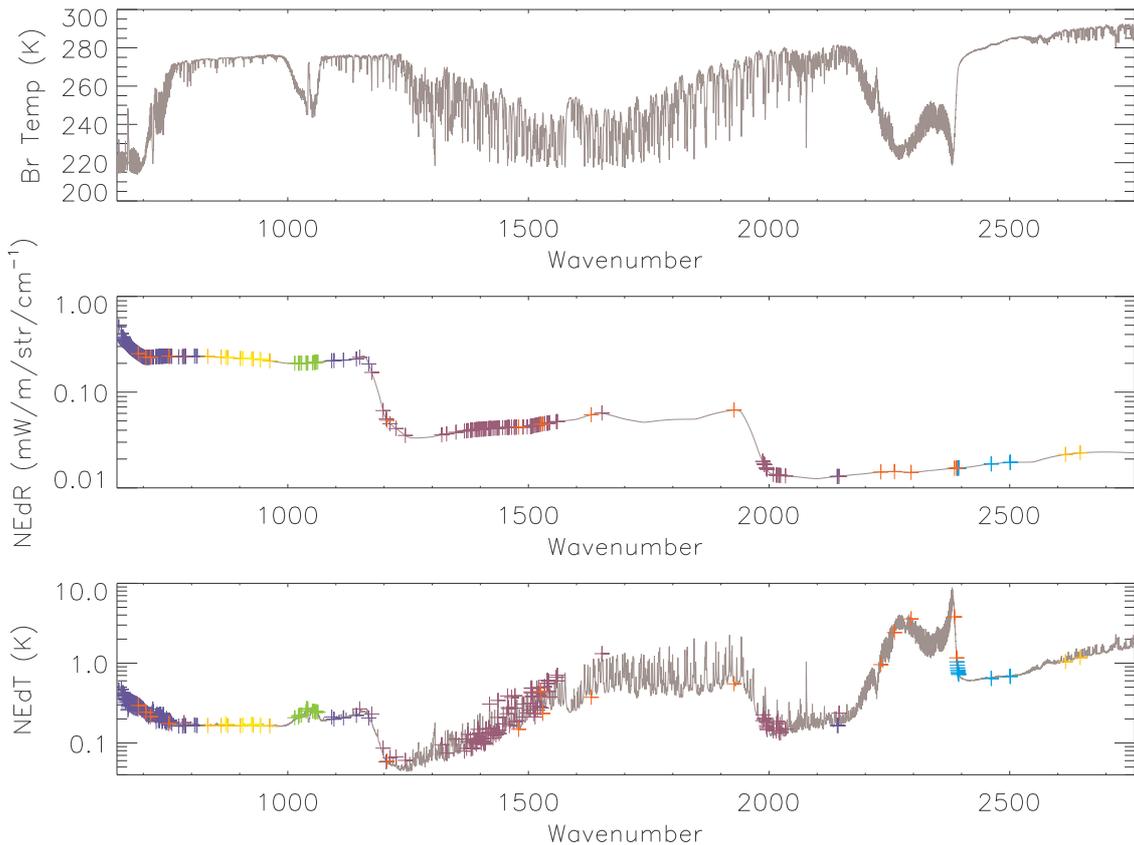


Figure 2: IASI channel selection and noise characteristics. Top: mean radiance spectrum from training set, converted to Brightness Temperature; Middle: Instrument random noise (1C) in radiance units; Bottom: Noise in Kelvin at the temperature corresponding to the mean radiance. The AAPP channel selection is shown by crosses. Colour key: **sounding**, **window**, **ozone**, **water vapour**, **solar**, **monitoring**.

Regional ATOVS Retransmission Services

During 2007 and 2008 there has been a major expansion in the RARS networks. These networks are co-ordinated by WMO and aim to make ATOVS data available to users within 30 minutes of the observation. There are now three networks operating:

1. EARS-ATOVS, operated by EUMETSAT and covering parts of Europe, northern Atlantic, USA, Canada, Greenland and the Arctic. This service was established in 2002.
2. Asia Pacific RARS, with stations in Australia, Japan, China, Singapore, Korea and Antarctica.
3. South American RARS, with stations in Brazil, Argentina and Antarctica.

Each network comprises a number of HRPT reception stations, each running AAPP. The AMSU, MHS and HIRS level 1c files are then BUFR encoded and made available to users, typically via the GTS or EUMETCast. EUMETSAT also operate an AVHRR retransmission service, also based on AAPP.

In order to ensure global/local consistency, the NWP SAF monitors the incoming data and performs comparisons with the corresponding global data (typically received 2-3 hours later). For further details on the NWP SAF monitoring activities, see

http://www.metoffice.gov.uk/research/interproj/nwpsaf/ears_report/index.html .

Forecast impacts of using these more timely data have been shown to be positive (Candy, 2008), with potential for further improvement as new stations are established, especially in the southern hemisphere. For the current status of RARS, see <http://www.wmo.int/pages/prog/sat/RARS.html> .

NPP and NPOESS

NPP is scheduled for launch in June 2010 and will contain a new suite of instruments, including CrIS, ATMS and VIIRS. It is planned to extend AAPP to accept data from these instruments – i.e. to develop 1d products for ATMS and CrIS that are analogous to the 1d products for AMSU/MHS and IASI.

AAPP will not process the direct broadcast data directly but the intention is that AAPP version 7 will be able to ingest the level 1 radiances generated by the *International Polar Orbiter Processing Package (IPOP)*, being prepared jointly by IPO, NASA and the University of Wisconsin (see <http://directreadout.gsfc.nasa.gov/index.cfm?section=technology&page=IPOP>). These data will be in HDF-5 format.

AAPP will also be able to ingest the BUFR format radiances that will be distributed through the NPOESS Data Exploitation (NDE) project. There is currently a proposal to redistribute VIIRS, ATMS and CrIS data to European users via EUMETCast.

A key requirement for NWP is that users have the flexibility to choose an appropriate effective spatial resolution for the ATMS 50GHz channels – which have a beam width of 2.2° and are sampled every 1.1° cross-track. For temperature sounding, users will often want to convert this data to an AMSU-A-like resolution (3.3° beam width), with low noise. On the other hand, for precipitation imaging there will be an interest in retaining the narrow beam width. Therefore AAPP will include beam width manipulation as an option, as well as the ability to map ATMS to CrIS.

In brief, the proposed technique is as follows:

1. With ATMS at its native spatial sampling, and treating each channel separately, perform a 2-D Fourier Transform (FT).
2. Multiply the transformed image by a pre-computed function that will broaden the effective beam shape. Gaussian beam shapes can be assumed when generating this function.
3. FT back to the image domain (still heavily over-sampled)
4. Interpolate to the CrIS sample positions if required, or re-sample at the required output grid.

Step 2 is illustrated in Figure 3. Note that we have attenuated high spatial frequencies, thereby reducing the noise; the RMS of the 2-dimensional ratio curve gives the noise reduction. The noise reduction factor is ~0.3 in the case illustrated – which should be sufficient to give AMSU-A-like noise levels for ATMS (~0.15K for the lower tropospheric temperature sounding channels). Some narrowing of the 23.8 and 31.4 GHz beam widths (from 5.2° to about 4.5°) will also be possible using this technique.

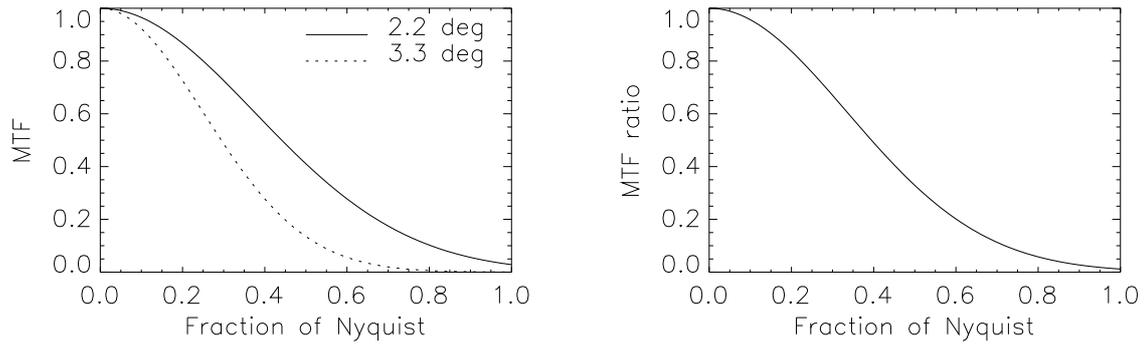


Figure 3: Beam shape manipulation for ATMS. Left: Spatial frequency response (Modulation Transfer Function, or MTF) for Gaussian beams of 2.2° and 3.3° beam width, sampled at 1.1°. Right: Ratio of the two response functions – to be used to multiply the FT of the input image. This is a 1-dimensional cross-section through a 2-D function.

The CrIS scan pattern is illustrated in Figure 4. AAPP will have the option of mapping ATMS to this scan pattern.

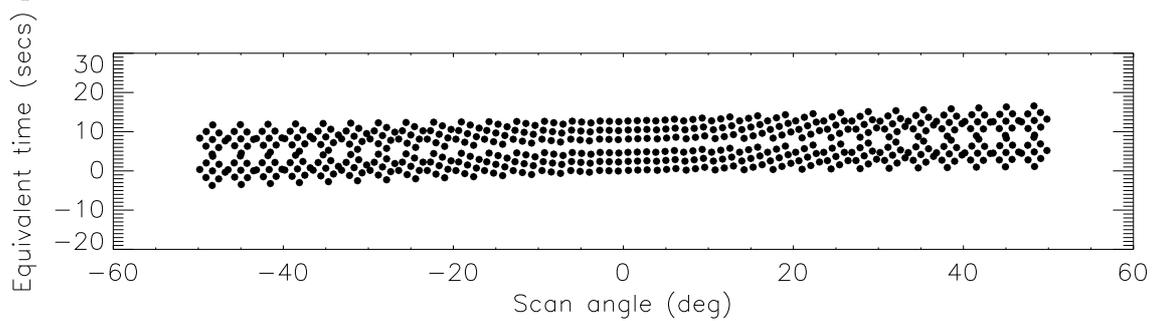


Figure 4: Scan pattern for CrIS

Other developments

During 2008 and 2009, the following enhancements to AAPP version 6 are planned:

- Support for NOAA-N prime, scheduled for launch in February 2009
- A new version of the MAIA AVHRR cloud mask, supporting the AVHRR cluster analysis which forms part of the IASI level 1c dataset.

Conclusions

AAPP version 6 is used operationally in many centres worldwide for processing direct-readout, regional and global data from the NOAA and MetOp satellites. FY-1D capability has recently been added.

AAPP is a key component of the RARS networks, which have undergone major expansions during 2007 and 2008. Global-local consistency is monitored by the NWP SAF.

The next AAPP major release (v7) will support NPP, due for launch in 2010.

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