THE CURRENT STATUS OF THE AATSR PROCESSING ALGORITHMS AND DATA PRODUCTS

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ABSTRACT

The AATSR ground segment processor is a crucial component of the AATSR system. Although the AATSR processor makes full use of the ATSR series heritage, a number of improvements have been incorporated both prior to and in the course of the ENVISAT mission, including the retrieval of Land Surface Temperature (LST). This paper describes the current status of the AATSR algorithms and data products, and describes current and future developments, including improvements to the LST algorithm, and the cloud clearing over land, and new SST retrieval coefficients.

1 INTRODUCTION

The Advanced Along-Track Scanning Radiometer (AATSR) is the third in the series of radiometers that includes the Along-Track Scanning Radiometer ATSR that flew on ERS-1 and its successor ATSR-2. Its primary objective is the collection of accurate and precise global measurements of Sea Surface Temperature (SST), which will continue the consistent, long-term set of global SST measurements from ATSR-1 and ATSR-2.

The processing algorithms for AATSR are based on those developed for ATSR and ATSR-2, and make full use of the ATSR series heritage. However, enhancements have been made, particularly in the area of image mapping (regridding) and in connection with improved provision for land products, including the retrieval of land surface temperature and NDVI, and the provision of topographic corrections for pixels over land.

2 UPDATE HISTORY

Although many of the updates to the AATSR operational processor since the launch of ENVISAT have been aimed at fixing problem reports, and these are described in the Product Disclaimers, others have represented genuine enhancements to the processor. Table 1 shows the major algorithm changes that have been incorporated in the processor.

<table>
<thead>
<tr>
<th>Date</th>
<th>Processor Version</th>
<th>Principal Enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002 June</td>
<td>V5.02</td>
<td>New Browse algorithm</td>
</tr>
<tr>
<td>2003 February</td>
<td>V5.55</td>
<td>New VISCAL scheme</td>
</tr>
<tr>
<td>2004 January</td>
<td>V5.58</td>
<td>Land surface temperature retrieval</td>
</tr>
</tbody>
</table>

An update early in the mission introduced improvements to the Browse Product. The AATSR Browse product was a new product based on the IONIA Scheme [1]; it did not reflect any ATSR-2 heritage and had not been fully developed in the pre-launch stage. The improvements were therefore motivated by experience with real AATSR data. It is unlikely that many users will have encountered the earlier form, so that the impact of this change on users will be marginal; however, it should be noted that the original form of the AATSR Product Handbook (still current at the time of writing) describes the original form, so caution is required.

The second major algorithm change listed in Table 1 affected the visible calibration algorithm. Shortly after launch it emerged that the ATSR-2 algorithm for extracting the visible calibration signal did not work with AATSR data because of a subtle change to the telemetry format. A new algorithm was thus required. The direct impact on the Level 1b products was that the calibration GADS was absent from the products processed prior to the introduction of the new
algorithm; the impact on the calibration of the channels was indirect, since it impacted the generation of ATS_VC1_AX files used for this purpose.

The principal change at Level 2 is the introduction of the new land surface temperature retrieval algorithm at processor version 5.58. This represents an important new product, and is described further below.

Table 2. Principal changes to auxiliary files.

<table>
<thead>
<tr>
<th>Date</th>
<th>File</th>
<th>Auxiliary data</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002 November</td>
<td>ATS_CH1_AX</td>
<td>New CH1 with updated misalignment</td>
</tr>
<tr>
<td>2004 August</td>
<td>ATS_PC1_AX</td>
<td>New PC1 with revised solar irradiance</td>
</tr>
<tr>
<td>2005</td>
<td>ATS_GC1_AX</td>
<td>New GC1 to correct 1.6 micron non-linearity</td>
</tr>
</tbody>
</table>

The principal changes to the auxiliary files that affect product quality are summarised in Table 2; they are as follows.

Level 1B Characterisation Data (ATS_CH1_AX). This file contains, among other things, parameters representing the misalignment of the instrument relative to the platform attitude model. These parameters affect the pixel geolocation model, and must be tuned in orbit to optimise the geolocation. The revised file improved the geolocation, and the alignment of the nadir and forward view images, substantially.

Level 1B Configuration Data (ATS_PC1_AX). This file contains a variety of parameters, mostly of limited interest to the user. Revisions within the lifetime of AATSR have included updates to the parameters that govern the visible calibration, related to the algorithm revision discussed above. However, one change involved changes to the solar irradiation values. These values are not used in product processing, but are provided in the VISCAL GADS for off-line use. The new file includes more up-to-date values.

Level 1B General Calibration File (ATS_GC1_AX). This file contains the look-up tables and parameters for calibration of the AATSR channels. It was updated to correct a scaling error that meant, in effect, that the non-linearity correction was not being applied to the 1.6 micron channel of AATSR.

3 LAND SURFACE TEMPERATURE ALGORITHM

The specifications of the AATSR Level 2 products define fields for the Land Surface Temperature (LST), but the original version of the AATSR operational processor did not include an algorithm for LST, which was added at processor version V5.58.

The definition of the LST algorithm [2] selected for AATSR is based on work by Prata [3] to develop algorithms to estimate land surface temperature from ATSR and AVHRR. These algorithms are based on radiative transfer theory applied to the exchange of radiation between the surface and atmosphere, and have been subjected to a thorough validation using a network of ground-truth sites across Australia.

The basic algorithm for LST retrieval is:

\[
LST = a_0 + b_0(T_{11} - T_{12})^n + (b_0 + c_0)T_{12},
\]  

(1)

where \(a_0, b_0, c_0\) are coefficients that depend on the land surface characteristics, viewing angle, and atmospheric water vapour, and \(T_{11}\) and \(T_{12}\) represent the brightness temperatures in the 11 and 12 micron channels respectively, and where the index \(n\), included to permit an additional tuning of the algorithm, depends on the incidence angle \(\theta\) as follows:

\[
n = 1/\cos(\theta / m),
\]  

(2)

where \(m\) is an empirical constant. Currently, the value \(m = 5\) is adopted. Equation (1) reduces to a standard split-window algorithm when \(n = 1\). If \(T_{11} - T_{12}\) is negative, then the term \((T_{11} - T_{12})^n\) in (1) is complex. This case can certainly arise in practice. The solution adopted is to set \(n = 1\) if \(T_{11} < T_{12}\).
The essence of the algorithm is to apply Equation (1) above to the 11 and 12 micron brightness temperatures in the nadir view. The retrieval coefficients $a_0$, $b_0$, $c_0$, depend on surface characteristics and atmospheric water vapour. Their values must reflect the complex variability of the surface, and this is achieved by means of look-up tables which define the local characteristics of the surface, and the local climatology, for each cell of dimension 0.5° in latitude by 0.5° in longitude. For each cell, look-up table entries define the following quantities:

- The surface classification within the cell. The cell is assigned to one of 14 surface types, represented by an integer in the range 1 to 14.
- The vegetation fraction $f$ ($0 \leq f \leq 1$) representative of the cell. This quantity has a seasonal variation that is represented in the tables by defining 12 values of $f$, one for each calendar month. The basis of the definition of this variation is defined in [2].
- The monthly mean precipitable water at the centre of the cell. Again 12 values are given, one for each month, to represent the seasonal variation.

A further table defines four sets of regression coefficients $a$, $b$ and $c$ for each surface type, corresponding to vegetation and bare soil, and to day and night conditions.

Initial validation of the LST yielded encouraging results [4], however, the LST algorithm retains the potential for further improvement, and some open issues remain that should be borne in mind by users of the LST product. These issues are described in the following sub-sections. Developments of the LST algorithm to address them are in hand.

### 3.1 Processing Over Lakes

The current LST auxiliary file (ATS_LST_AX) includes an inland lakes class (surface type 14) in the surface type mask, together with the corresponding inland lake retrieval coefficients. However, the AATSR land/sea database that is used for land/sea flagging by the Level 1b processor flags inland lakes as sea. LST is only retrieved for pixels flagged as land in the land/sea database, and so lake retrieval is not attempted in the current implementation. The logic of the algorithm is to be restructured to ensure that it is.

### 3.2 Cloud Clearing

The AATSR cloud clearing algorithm [5] is optimised for use over sea, and its performance over land is not guaranteed; improvements to the cloud clearing over land are needed to maximize the value of the LST product. Some simple changes to the present scheme that might improve cloud clearing over land have been identified and are to be incorporated in the processing.

### 3.3 Pixels flagged as Cloudy

The AATSR Level 2 full resolution product is ‘switchable distributed’, meaning that the contents of the pixel fields depend on the land/sea and cloud flags. At present therefore LST is only calculated for pixels flagged as clear land, not for cloudy land pixels. Currently for cloudy pixels the corresponding field contains the infra-red brightness temperature in the 11 micron channel, as a placeholder for cloud top temperature. Therefore pixels wrongly flagged as cloud contain the 11 micron brightness temperature, not the LST.

Because of the limitations of the cloud clearing scheme over land, it is thought more useful to provide the retrieved LST for pixels flagged as cloudy land, so as to give a more homogeneous LST field. The pending revision of the LST algorithm will therefore calculate LST regardless of cloud state. This requires a revision of the definition of the product confidence flags, but given the limitations of the current cloud clearing scheme is a viable solution to the problem.
4 POTENTIAL IMPROVEMENTS TO SST RETRIEVAL

4.1 Revised retrieval coefficients

The theoretical basis underlying the generation of coefficients for SST retrieval is described in [6]. In brief, a linear regression is defined to relate the sea surface temperature to the measured brightness temperatures in the infra-red channels of ATSR:

\[ T = T_0 + \sum_{i=1}^{n} a_i T_i \]  

(3)

where \( T \) is the SST, \( T_0 \) is a constant offset, \( n \) is the number of infra-red brightness temperature channels used in the retrieval, \( T_i \) is the brightness temperature in channel \( i \), and \( a_i \) are the retrieval coefficients.

To determine the coefficients \( a_i \), a radiative transfer model is used to calculate theoretical brightness temperatures for each of member of an ensemble of atmospheric profiles with associated SST values. The coefficients of the best-fitting relationship of the form (3) are then defined by least squares fit of the SST to the modelled brightness temperature data. When the set of channels \( i \) includes both nadir and forward view channels a constrained fit is carried out to define coefficients that are ‘robust’ to the presence of stratospheric aerosol [7].

It follows that the retrieval coefficients depend on the radiative transfer code used, and in particular the molecular spectroscopy database that is used to define the absorption properties of the atmosphere. The retrieval coefficients currently in use (those in the pre-launch version of the auxiliary file) are based on the same atmospheric spectroscopy as was used for ATSR-1 and ATSR-2, which pre-dated the more recent releases of the HITRAN molecular spectroscopy database. The introduction of more recent atmospheric spectroscopy is therefore an obvious enhancement.

A new set of retrieval coefficients based on the HITRAN 2000 database has recently been derived. According to a preliminary assessment of these coefficients at the UK Met. Office (A. O’Carroll, private communication), the new coefficients have improved the retrievals by eliminating the bias (of about 0.15K) between the 4-channel and 6-channel retrievals observed with the pre-launch coefficients. It is expected that the new coefficients will be released shortly.

4.2 Latitude dependent bias correction

The SST retrieval coefficients used for dual view retrievals have been derived using the aerosol robust treatment described in [7], and are global; that is to say, the same coefficients are used at all latitudes. As a result there is a latitude-dependent bias between the retrievals that use the 3.7 micron channel and those that do not. Thus although the mean retrieval error averaged over the ensemble of atmospheric profiles is zero, if the retrieval error is plotted as a function of the latitude of the profile a characteristic variation can be seen.

The effect is particularly pronounced in the ‘4-channel’ retrievals that use only the dual view 11 and 12 micron channels. It is much weaker in the ‘6-channel’ retrievals that also use the 3.7 micron data in both views. Since the latter are not used during the day, it is important to establish the relationship between the two retrievals, and to derive a correction that can be applied off-line to the 4 channel SST retrievals to bring them into line with the 6 channel retrievals.

The current operational retrieval coefficients for AATSR were determined using a set of 1290 atmospheric profiles sampled at intervals of 15 degrees in latitude, insufficient for a useful operational correction. To determine the latitude correction a larger profile set sampled at 5 degrees in latitude has been used. This profile set, supplied by C.J. Merchant (private communication), contains 4528 profiles derived from ECMWF re-analysis fields from 1990. The latitude correction has been derived by applying the operational retrieval coefficients to the brightness temperatures derived from this profile set. In order to ensure that the derivation is self-consistent, the same version of the radiative transfer model was used as was used in the derivation of the operational coefficients themselves. To assess the sensitivity of the results to enhancements to the spectroscopic data used by the radiative transfer model, the computation has been repeated using the more up to date molecular spectroscopic data.
The current AATSR operational dual view retrieval coefficients have been applied to the model infrared brightness temperatures for 4-channel and 6-channel retrievals at both the swath centre and swath edge. Thus, for each profile \( k \) a retrieved sea surface temperature \( T(k) \) has been derived. From this the retrieval error

\[
\Delta T_k = T_0(k) - T(k)
\]  

(4)

has been calculated using both the 4 and 6 channel retrieval algorithms, where \( T_0(k) \) is the actual surface temperature from the ECMWF analysis corresponding to profile \( k \). \( \Delta T_k \) thus represents the correction to be added to the retrieved temperature to give the true SST. Note that the coefficients used for the present calculations are those for the averaged SST retrieval; equivalent calculations for the gridded SST retrieval are not reported here.

To determine the latitude dependent bias, the retrieval errors were averaged over the profiles at each latitude separately. This analysis yields the retrieval bias as a function of latitude. Fig. 1 shows the results based on the original spectroscopy for the swath centre. The solid and dashed curves show the bias for the 4 and 6 channel retrievals respectively. Clearly the latitude variation of the six-channel retrieval is marginal, but the four-channel retrieval shows a characteristic variation of approximately 0.1 K amplitude.

The difference between the retrievals, after smoothing, is shown as the dot-dashed curve in Fig. 1. This is

\[
\Delta \overline{T}_{k,4} - \Delta \overline{T}_{k,6} = \overline{T}_0(\varphi) - \overline{T}_4(\varphi) - \{\overline{T}_0(\varphi) - \overline{T}_6(\varphi)\} = \overline{T}_0(\varphi) - \overline{T}_4(\varphi)
\]  

(5)

where the bar denotes the average over all values of \( k \) at latitude \( \varphi \), and the subscripts 4 and 6 denote the 4 and 6 channel retrievals respectively. This is the quantity that must be added to the 4-channel retrieval to give the 6-channel retrieval, and represents the required correction.
The retrievals show a substantial spike at 80 S latitude. Investigation shows that this spike is derived from a single invalid profile that falls on the Ross Ice Shelf. Clearly it is not appropriate to include this datum in the correction. The difference in Fig. 1 shows the correction after removing this point and applying a simple Hanning filter to smooth the data. The resultant curve represents the correction that is to be added to the 4-channel (daytime) retrieval to align it with the 6-channel (night-time) retrieval.

If the calculation is repeated using the swath edge coefficients, the results differ very little from those for the swath centre shown in Fig. 1. It is thus sufficient to use a single correction for all pixels regardless of their position in the swath. Similarly the latitude dependence is not sensitive to the set of coefficients used in its derivation, provided that the coefficients are consistent with the model brightness temperatures to which they are applied (otherwise a global bias will be introduced). Thus the curve derived for the new coefficients can also be used for the historic data processed with the pre-launch coefficients.

It is not planned to incorporate this correction in the processing algorithms, but it is intended to formally release the tabular correction shortly, so that users can apply it off-line to the brightness temperatures.

5 CONCLUSION

This paper has summarised the current state of the AATSR products and processing algorithms. The AATSR processing system has been subject to very few problems requiring processor updates in the mission to date, but a number of enhancements have been implemented since launch.

A land surface temperature algorithm, based on the work of Prata [2, 3], has been implemented in the AATSR reference and operational processors. A validation programme for the LST yielded encouraging results [4], and several improvements are planned in the near future.

New SST retrieval coefficients incorporating up-to-date molecular spectroscopy are expected to be released shortly, along with an off-line correction for the latitude dependent bias in the dual view retrieval that results from the use of global coefficients. It is hoped that these developments will enhance the value of the AATSR data set to the user community.

6 REFERENCES