ALGORITHM VERIFICATION FOR AATSR: LEVEL 2 VERIFICATION

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ABSTRACT/RESUME

This paper describes the Level 2 algorithm verification activities undertaken at Rutherford Appleton Laboratory (RAL) in support of the commissioning of the Advanced Along-Track Scanning Radiometer (AATSR) during the ENVISAT Commissioning Phase. The algorithm verification is based on study of AATSR products from the AATSR Instrument Processing Facility (IPF), and is intended to confirm that the processing algorithms used by the AATSR Operational Processor (OP) operate correctly when presented with real AATSR data. The Level 2 algorithm verification to date has been based on a set of verification products supplied specifically for the purpose; it is intended to extend the testing to a selection of routinely distributed products at a later date.

No errors in the product format, headers or Annotation Data Sets have been identified, other than those associated with already known Level 1B issues; these do not require any update to the Level 2 processor. No errors have been identified in the gridded (GST) product although further scrutiny is desirable to increase the range of conditions tested. In the averaged (AST) product, four problems have been identified. None are blocking; all result from relatively simple coding errors, and corrective action is in hand. Checks of the Land MDS are still outstanding, and automated testing should be used to extend the range of conditions tested, including tests on Level 2 products now being distributed. Subject to these qualifications, the AATSR Level 2 processor has been successfully verified.

1 INTRODUCTION

A previous paper [1] described the programme of algorithm verification activities undertaken at Rutherford Appleton Laboratory (RAL) in support of the commissioning of the Advanced Along-Track Scanning Radiometer (AATSR) during the ENVISAT Commissioning Phase. This paper presents the continuation of that work, concentrating on the verification of the Level 2 products.

The purpose of the AATSR Algorithm Verification is to confirm that the processing algorithms used by the AATSR Operational Processor (OP) operate correctly when presented with real AATSR data, and that the products are being correctly generated. The task is distinct from the validation of the geophysical products that is the subject of the AATSR Validation Plan [2]; the aim is to verify the operation of the processor, and to identify any problems that were not, for whatever reason, discovered during factory acceptance testing of the OP.

2 OVERVIEW OF ALGORITHM VERIFICATION

The previous paper [1] outlined the basis of the algorithm verification. The algorithm verification is based on study of AATSR products from the AATSR Instrument Processing Facility (IPF). The test procedures used for algorithm verification are set out in the AATSR Algorithm Verification Plan, and the approach is to study a small number of products in detail, and to scrutinise these products for consistency at a given processing level, rather than to compare (for example) the Level 2 products or breakpoints with Level 1b products from which they were derived.

The verification plan did not envisage the use of products generated by the AATSR Reference Processor (RP) during algorithm verification, since it was not clear whether or not they would be available. In practice, however, RP products have been available, and some tests involving comparison with the equivalent RP product have been used.

The plan also envisaged that where ATSR-2 products of a given orbit were available, some limited qualitiative comparisons of the AATSR and ATSR-2 data might be made. Quantitative comparisons of the image products between the two instruments would present difficulties because of the different sampling grids used by the two instruments, and because of changes in the cloud field in the 30 minutes between the ENVISAT and ERS-2 passes over a given region. However, these difficulties would not affect a comparison of averaged products, and although it did not form part of the original verification plan, a comparison of the AATSR Averaged (AST) Product with the equivalent ATSR-2 data is now planned to cover 4 full orbits of data.

3 AATSR PRODUCTS FOR VERIFICATION

Algorithm verification has been based in the main on the analysis of AATSR products generated by the AATSR Operational Processor. Reference [3] gives a brief introduction to the AATSR products and processing scheme; full specifications of the Level 2 processing algorithms and the product formats are given in the AATSR Level 2 Detailed Processing Model [4] and the AATSR Input / Output Data Definition [5] respectively. Table 1 summarises the AATSR products at Level 1b and Level 2 generated by the IPF. All products are to be subject to algorithm verification.

Table 1: AATSR Products

Level	ID	Description	Availability
1b	ATS_TOA_1P	Gridded Brightness Temperature/Reflectance (GBTR)	NRT: 3 hours Off-line: 2 weeks
1b	ATS_AST_BP	Browse (nadir view only, 4 km resolution)	NRT: 3 hours to 3 days Off-line: 3 days
2	ATS_AR__2P	Average Surface Temperature (AST)	NRT: 3 hours Off-line: 2 weeks
2	ATS_NR__2P	Gridded Surface Temperature (GST)	NRT: 1 to 3 days Off-line: 2 weeks
2	ATS_MET_2P	Meteo Product	NRT only

AATSR algorithm verification to date has been based on a batch of 8 AATSR products (the verification products) comprising the Level 1b (GBTR), Level 2 (GST and AST), and Meteo products from each of two orbits on 2002 May 21. Table 2 below lists these products.

Table 2. AATSR products supplied for the verification tests.

Product	Orbit	File name	File size (bytes)
GBTR	1165	ATS_TOA_1PNPDK20020521_112527_000066042006_00109_01165_0398.N1	835,648,091
GST	1165	ATS_NR__2PNPDK20020521_112527_000066042006_00109_01165_0398.N1	144,3838,691
AST	1165	ATS_AR__2PNPDK20020521_112527_000066042006_00109_01165_0398.N1	96,067,834
Meteo	1165	ATS_MET_2PNPDK20020521_112527_000066042006_00109_01165_0398.N1	9,737,994
GBTR	1170	ATS_TOA_1PNPDK20020521_193803_000066042006_00114_01170_0405.N1	835,694,571
GST	1170	ATS_NR__2PNPDK20020521_193803_000066042006_00114_01170_0405.N1	144,385,171
AST	1170	ATS_AR__2PNPDK20020521_193803_000066042006_00114_01170_0405.N1	93,769,538
Meteo	1170	ATS_MET_2PNPDK20020521_193803_000066042006_00114_01170_0405.N1	9,382,548

Each product comprises a full orbit of near real time (NRT) data whose starting points fall within absolute orbits 1165 and 1170. (Note that because these are NRT data, the products do not start at an ascending node.)

4 FORMAT AND HEADER VERIFICATION

Format verification for both Level 1b and Level 2 products is intended to verify that the products are correctly written. Errors in the physical format of the products (such as records being written with the wrong length) might have the result that the products could not be read properly by the software tools used for algorithm verification. To identify any such errors a software tool was prepared [1] to read product headers, and extract and analyse Data Set Descriptor (DSD) information.

As reported in [1], this test utility was run on each of the files specified in Table 2 in turn. The test was successful on each file. No format errors were reported, and the calculated file size matched that given by the directory listing in each case. It was also verified that all ADS and MDS defined in the IODD [5] are present in the Level 2 products.

Following format verification, the contents of the header fields should be checked to ensure that both the Main Product Header (MPH) and Specific Product Header (SPH) have been correctly written.

For all instruments the MPH has the same form, while in the case of the case of the AATSR Level 2 products, with one exception the contents of the Level 2 SPH are identical (where present) to those of the Level 1b product from which they are derived. Since the Level 1b product headers have been validated previously, it is sufficient, to verify the Level 2 product headers, to identify and account for any differences between the Level 2 product header and the corresponding Level 1b product header. Verification criteria can be formulated as follows; with the exception of certain product specific fields:

- The MPH and SPH of the Level 2 Gridded (GST) product should be identical to those of the Level 1B product from which it was derived.

- The SPH of the Averaged (AST) and Meteo products should be identical, and differ from that of the GST product only by the omission of the tie point specifications, which apply only to the gridded product.

A program was therefore written to extract the headers from each product, and the UNIX *diff* function was used to compare the extracted headers of each Level 2 product in Table 2 with those of the corresponding Level 1b product (that for the same orbit).

In the case of the Main Product Headers, no differences were found other than the expected differences in the product-dependent fields. These are the product name field (field 1) itself, the processing time (field 7), and the fields which relate to product characteristics; product size, SPH size, number of data sets and number of Data Set Descriptors (DSD). In all these cases the field values were correct.

Comparisons of the specific product headers showed no material differences between the SPH of the GST product and that of equivalent Level 1b (GBTR) product other than the SPH descriptor field, which is specific to the product. Similarly, apart from the expected difference in the SPH descriptor field and the omission of the tie point specifications, the SPH of the AST and Meteo products were identical to the GST SPH.

Some minor errors in the headers of the Level 1b products were identified during Level 1b Algorithm Verification [1]. The agreement between the Level 1b and Level 2 headers implies that, as would be expected, these errors are also present in the Level 2 product headers. This does not invalidate the verification of the Level 2 SPH, since the Level 2 SPH is derived from the Level 1b product SPH (there is no other source of the information). Thus it is logically correct to require that the Level 2 SPH be identical to that at Level 1b, even if the latter is wrong. The Level 1b errors will be corrected in the next release of the processor, and the Level 2 headers should automatically be corrected as a result. No correction to the Level 2 processor is required.

5 GRIDDED PRODUCT VERIFICATION

The Level 2 Gridded Surface Temperature (GST) product includes 7 Annotation Data Sets (ADS) and a single Measurement Data Set (MDS). With the exception of the Summary Quality ADS (SQADS), the Annotation Data Sets should be identical to those of the Level 1b (GBTR) product from which the GST product was derived. Thus although specific tests are defined in the Verification Plan for each distinct ADS, in practice it is sufficient to verify these ADS

by verifying that each is identical to its counterpart in the Level 1b product, and this is the approach that has been taken here. The ADS and MDS verification are discussed in turn in the following sections.

5.1 Verification of ADS

5.1.1 Summary Quality ADS

The Summary Quality ADS (SQADS) contains packet validation error counts that indicate the occurrence of various error conditions in the telemetry source packet, together with some quality indicators derived during Level 2 processing. It differs from the SQADS of the Level 1b product by the addition of four fields of Level 2 quality information.

The packet validation error counts are carried through directly from Level 1b processing, and so the corresponding fields in the Level 2 ADS should be identical to the corresponding fields in the Level 1b ADS. Only the fields containing the quality indicators derived during Level 2 processing should differ; there are four of these:

- Percentage of cloudy pixels;
- Percentage of pixels showing NDVI invalid;
- Percentage of pixels showing SST (nadir view) invalid;
- Percentage of pixels showing SST (dual view) invalid.

Each record of the SQADS refers to a 512 row segment of the image, and so the percentages above refer to an image segment (or frame) of 512 × 512 pixels. The percentages are expressed in units of 0.01%, so the maximum value in these fields should be 10,000, corresponding to 100%.

For each of the GST products in Table 2, the SQADS was compared with the SQADS from the Level 1b product for the same orbit using a automated comparison tool. Each field was compared separately. As a result of this comparison we would expect to find the following:

- In the case of the packet validation count fields, which are carried over from the Level 1b processing, corresponding fields in the GST and GBTR products will be identical.
- In the case of the quality indicators derived during Level 2 processing, the Level 2 ADS fields should contain a positive value between 0 and 10,000, and the values should be realistically related to the image data.

Both of these criteria were satisfied. The packet validation count fields showed no differences between the Level 2 and Level 1b products. The Level 2 quality indicator fields showed values that fell within the required range between zero and 10,000 (corresponding to 100%). The distribution of values was qualitatively reasonable; for example, zero values were found in the records corresponding to the null frames at the start of the product, and the fraction of pixels showing NDVI invalid was 100% at night, when a valid NDVI cannot be derived.

It was found during Level 1b validation that the only non-zero packet validation fields in the SQADS were those corresponding to scans affected by scan jitter, and other invalid scans were not flagged in the SQADS [1]. The same will therefore be true of the Level 2 SQADS. However, this does not invalidate the present work, since the packet validation fields of the Level 2 SQADS are taken from the Level 1 product. The verification criterion is therefore that the Level 2 values should agree with those from the Level 1b product, not that they should be correct. When the Level 1b processor is corrected, the Level 2 values should automatically be valid.

It is of course possible that some packet validation words are not being copied, but that this is being masked by the fact that they are not set in the Level 1b product. This should be checked when corrected products become available, but subject to this proviso, the algorithm verification has found no errors in the Level 2 SQADS.

5.1.2 Other ADS

In addition to the SQADS, the GST product includes six other ADS as follows:

- Geolocation ADS
- Scan Pixel x and y ADS
- Solar and Viewing Angles ADS (nadir and forward views)
- Scan and Pixel Number ADS (nadir and forward views)

As noted above, it is logically sufficient to verify these by confirming that they are identical to their counterparts in the Level 1b product, and this has been done. For each of the two GST products listed in Table 2, each of the above ADS in turn has been compared to the corresponding Level 1b ADS using an automated comparison. In no case was any discrepancy found between the Level 1b and Level 2 ADS.

Thus the results of the Level 1b verification apply to the GST Annotation Data Sets. As reported in [1], application of the Level 1b verification tests to the Level 1b (GBTR) Annotation Data Sets found no major errors, but identified a few minor deviations from the Detailed Processing Model [6]. It follows that these deviations will also be present in the GST product. Most of these discrepancies will be addressed in the next release of the OP, and it follows that the problems corrected in the Level 1b processor will automatically be corrected in the Level 2 products, since the Level 2 ADS are derived from the Level 1b product; again no correction to the Level 2 processor is required.

5.2 Verification of MDS

Using a product comparison utility, the full resolution Level 2 (GST) image products ATS_NR_2P listed in Table 2 have been inspected and compared with the equivalent RP product (i.e. the product obtained by running the Level 2 RP with the Level 1b Verification Product as input). Visual agreement between the images and between histograms of pixel values is good, and no obvious artefacts have been observed, while the surface type flagging matches the superimposed coastline. (The coastline is based on the Geolocation ADS, so the latter is a test of consistency.) Nonetheless, further quantitative scrutiny is desirable, to enhance product confidence.

6 AVERAGED PRODUCT VERIFICATION

The Averaged Surface Temperature (AST) Product contains 16 Measurement Data Sets, ordered by surface type and resolution as shown in Table 3.

Table 3. AST Product Data Sets

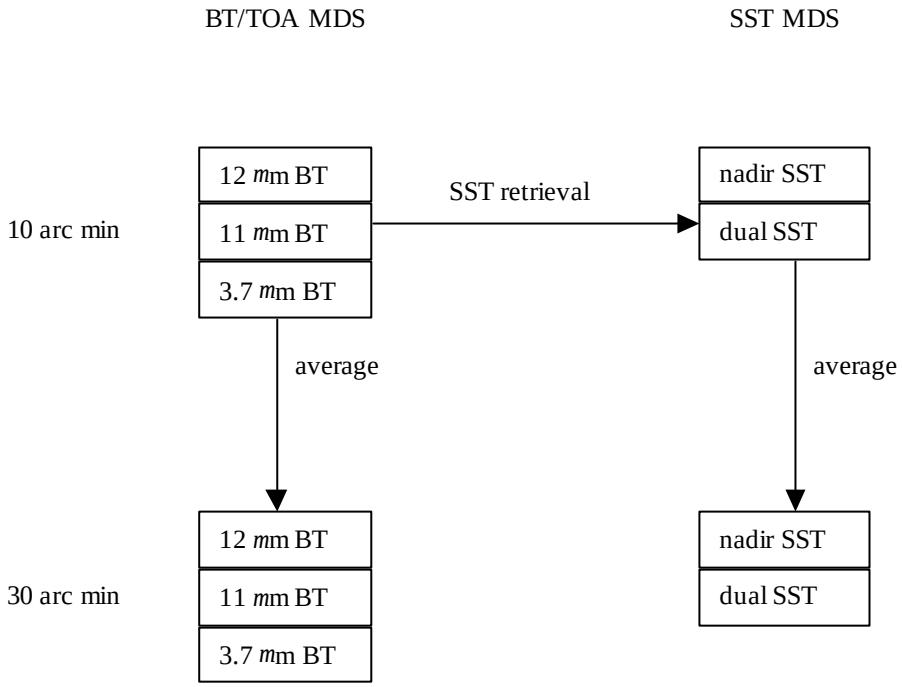
MDS	Content / Purpose	MDS	Content / Purpose
1	Sea Surface Temperature (SST) record, 50 km cell	9	BT/TOA Land Record, 50 km cell
2	SST record, 17 km cell	10	BT/TOA Land Record, 17 km cell
3	SST record, 10 arc minute cell	11	BT/TOA Land Record, 10 arc minute cell
4	SST record, 30 arc minute cell	12	BT/TOA Land Record, 30 arc minute cell
5	Land Surface Temperature (LST) record, 50 km cell	13	BT/TOA Sea Record, 50 km cell
6	LST record, 17 km cell	14	BT/TOA Sea Record, 17 km cell
7	LST record, 10 arc minute cell	15	BT/TOA Sea Record, 10 arc minute cell
8	LST record, 30 arc minute cell	16	BT/TOA Sea Record, 30 arc minute cell

Both surface and top-of-atmosphere (TOA) MDS are included in the product. The surface temperature data sets provide, for sea cells, nadir and dual view sea surface temperatures, and for land cells, land surface temperature and NDVI. Data sets are provided at two different resolutions and using two different averaging schemes. Measurement data sets are provided at 0.5° × 0.5° and 10 × 10 arc minute resolution with respect to a latitude/longitude grid; these data sets provide continuity with existing ATSR-2 products. Other data sets contain data averaged over equal area cells of nominal dimensions 50 × 50 km and 17 × 17 km, aligned with the satellite ground track, to give an alternative averaged product based on equal area cells. Land and sea data are provided in separate data sets.

The basic verification tests on the AST data sets look for internal consistency between the fields in the different data sets. Consider the sea records at 10 /30 arc minute resolution. The relationships between the principal quantities in the data sets are shown in Figure 1. Within the BT/TOA data sets, the brightness temperature (BT) values at 30 arc minute resolution are obtained by averaging 10 arc minute brightness temperatures. Similarly within the SST data sets the nadir

only and dual view SST values at 30 arc minute resolution are obtained by averaging the 10 arc minute SST values. Finally the 10 arc minute SST values are obtained by applying a retrieval algorithm to the 10 arc minute BT values in the corresponding cell. Similar relationships apply to the land data sets and to the data sets at 17 / 50 km resolution.

Figure 1. The relationship between 10 / 30 arc minute MDS in the AST product.



Thus verification criteria can be formulated as follows. For each surface type and averaging scheme separately:

- The 30 arc minute [50 km] average BT / reflectance should equal the average of the corresponding 10 arc minute [17 km] cell values.
- The 30 arc minute [50 km] average surface temperature / NDVI should equal the average of corresponding 10 arc minute [17 km] cell values.

For AST sea records:

- The averaged SST should be correctly related corresponding averaged BT values.
- The dual view and nadir only SST values should be consistent; their difference should show a realistic range of values.

For AST land records:

- NDVI should be correctly related to corresponding averaged reflectance values from the BT / TOA records.
- LST should match the corresponding averaged BT value.

In the following sub-sections we describe the results of verification of the BT /TOA and Surface Temperature data sets separately. Both manual checks of selected records, and automated checks of a range of records (using IDL scripts)

have been used. Manual checks are somewhat laborious, but such a check on a single record is sufficient to identify a problem. An automated check of a range of records extends the range of conditions checked, and reduces the probability of unrecognised errors. Note that there are no Annotation Data Sets in the AST product, and so no ADS verification is required.

6.1 Averaged Surface Temperature Data Sets

Manual checks on 17 / 50 km sea records have shown that the 17 km nadir only SST agrees with an independent IDL retrieval using infrared BTs from corresponding BT / TOA record. However, they have also shown two anomalies:

1. The 17 km AST confidence word is anomalous.

2. The 17 km dual view SST on ascending arcs differs from corresponding nadir SST by an unrealistically large amount, and is clearly invalid. BT differences (nadir - dual) between 5.41 and 19.68 K are observed in one section.

Both these problems are under investigation, and are expected to be corrected in the next release of the processor.

Other tests have shown that the relationship between the 50 km and 17 km cells is correct. Both the nadir and dual view averaged SST in 50 km cells agree with average of the component 17 km values, and the standard deviations in 50 km cells are valid.

The verification tests of the 10 / 30 arc minute sea records have shown no anomalies. Specifically, manual checks on the 10 and 30 arc minute sea records have shown that in the 10 arc minute records both nadir only and dual view SST retrievals agree with the independent IDL retrieval using infrared BTs from corresponding BT / TOA record, and that in the 30 arc minute cells, both nadir and dual view averaged SST agree with the average of the component 10 arc minute values, and the standard deviations are valid. These tests can be automated using IDL scripts, and this will be done to extend the range of the verification. Equivalent tests on land records are also planned.

6.2 BT / TOA Measurement Data Sets

Initial manual tests applied to the 10 / 30 arc minute sea records have verified that average clear sea BTs in the 30 arc minute cells agree with average of BT values in component 10 arc minute sub-cells. Automated tests have extended these tests to a wider range of records and to cloudy sea values. No discrepancies have been found. Equivalent tests on the 50 / 17 km MDS and Land MDS are pending.

6.3 Sub-cell latitude and longitude

In the course of applying the manual tests, it has been found that the latitude and / or longitude of the 10 arc minute sub-cells are calculated incorrectly when either is negative. The sub-cell, which is a small quadrilateral 10 arc minutes on each side, should be identified by the co-ordinates of its south-west corner, but when either of the co-ordinates is negative, the co-ordinates of a different corner are computed. The maximum error of a single sub-cell is therefore 10 arc minutes in each co-ordinate. It also follows that two adjacent sub-cells may be assigned the same co-ordinates when their common boundary is either the equator or the meridian.

This problem proves to be the result of a simple coding error, which will be corrected in the next release of the processor. Until the correction is in place, this error will also affect the Meteo product.

7 METEO PRODUCT VERIFICATION

The Meteo product contains a single MDS that is derived from the 10 arc minute resolution sea Measurement Data Sets of the Averaged (AST) Product. Specifically, each record of the Meteo Product MDS corresponds to a single 10 arc minute cell and contains the fields from the 10 arc minute cell Sea Surface Temperature MDS (MDS #3) plus the six clear sea infrared brightness temperatures (three channels each for the nadir and forward views) from the 10 arc minute cell BT/TOA sea record (MDS #15).

Algorithm verification for this product therefore consists in a comparing the product with the corresponding AST product, and checking that for each field of any 10 arc minute cell record, the field contents are the same as the contents in the corresponding fields of the AST product. In particular:

- Each infra-red brightness temperature field should equal the corresponding field in the AST product.
- The retrieved SST and related values should equal the corresponding field of the AST product.

Checks have found no discrepancies in the BT and SST fields. However, the two halves of the confidence word appear to be transposed with respect to the confidence word in the AST product. This problem is under investigation; when it is corrected, the impact on the BUFR form of the product must be established.

8 AUXILIARY FILE TUNING

The algorithm verification activity includes the tuning of the parameters in the auxiliary files used by the AATSR processor and the generation, where necessary, of new versions of the files. Only two auxiliary files are used by the Level 2 AATSR Processor. The situation with respect to these is as follows.

8.1 Level 2 Processor Configuration Data File ATS_PC2_AX

This file contains miscellaneous parameters including the brightness temperature thresholds for the AST product, and parameters that define the geometry of the averaged product.

No updating of this file is currently envisaged, but it will be straightforward to define any necessary changes that may be suggested by further inspection of the Level 2 products.

8.2 SST Retrieval Coefficient Data File ATS_SST_AX

The SST retrieval coefficients are derived from a radiative transfer modelling calculation; they are not subject to empirical adjustment. Any changes to this file will be the result of a new radiative transfer calculation, introduced to apply new physical parameters or modelling as a result of detailed validation studies.

No update of this file is envisaged as a result of the algorithm verification activity. If the AATSR validation were to suggest that different modelling assumptions were appropriate, an updated modelling calculation might be made.

9 SUMMARY

Verification tests have been applied to all the Level 2 AATSR IPF products listed in Table 2.

No errors in the product format, headers or Annotation Data Sets have been identified, other than those associated with already known Level 1B issues; the latter will be automatically corrected by the next release of the Level 1b processor, and do not require any update to the Level 2 processor.

No errors have been identified in the gridded (GST) product although further scrutiny is desirable to increase the range of conditions tested. In the averaged (AST) product, four problems have been identified. Software Problem Reports have been raised in these cases, and corrective action is in hand. All result from relatively straightforward coding errors, and they will be corrected in the next release of the processor.

Checks of the Land MDS are still outstanding, and automated testing should be used to extend the range of conditions tested, including tests on Level 2 products now being distributed. Subject to these qualifications, and to the correction of the problems above, the AATSR Level 2 processor has been successfully verified.

10 REFERENCES

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