AATSR

SCIENTIFIC REQUIREMENTS FOR THE

ADVANCED ALONG-TRACK SCANNING RADIOMETER

Abstract : This document describes the high level scientific requirements for the Advanced Along-Track Scanning Radiometer (AATSR). It is the top level requirement document from which the requirements on the instrument and the ground data processing are derived.

Approved by :

D. Llewellyn-Jones
on behalf of the AATSR Science Advisory Group

Compiled by

I. Parkes
on behalf of AATSR PI

Approved by :

D. Warrilow
on behalf of the funding agencies

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Global Atmosphere Division,
Department of the Environment,
Romney House,
43 Marsham Street,
London SW1P 3PY,
United Kingdom
Tel : +44 71 276 8674
Fax: +44 71 276 8509

AMENDMENT POLICY

This document shall be amended by releasing a new edition of the document in its entirety. The Amendment Record Sheet below records the history and issue status of this document.

AMENDMENT RECORD SHEET

ISSUE	DATE	DCI No	REASON
A	22 Apr 94	N/A	First draft
B	20 June 94	N/A	Second draft
C	26 Feb 96	N/A	Third draft, reviewed by SAG
D	21 May 96	N/A	Fourth draft
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1. INTRODUCTION

1.1. Purpose and Scope

This document defines the scientific requirements for the Advanced Along-Track Scanning Radiometer AATSR for flight on ENVISAT-1. It is the basis on which the AATSR Instrument Performance Requirements and the AATSR Data Processing Requirements are defined.

1.2. Structure of the Document

After this introduction, the document is divided into a number of major sections which are briefly described below:

2. Background to AATSR

This section provides a summary description of the ATSR series of instruments.

3. Scientific Requirements for Sea Surface Temperature measurements

This section describes the requirements for AATSR in order to provide scientifically useful measurements of Sea Surface Temperature.

4. Scientific Requirements for Land Remote Sensing

This section describes the requirements for AATSR in order to provide scientifically useful measurements over land.

5. Scientific Requirements for Other Research

This section describes the requirements for AATSR in order to provide other scientifically useful measurements.

GLOSSARY

The Glossary contains definitions of acronyms, abbreviations and terms used throughout the document.

1.3. Referenced Documents

The following is a list of documents with a direct bearing on the content of this report. Where referenced in the text, these are identified as RD.n, where 'n' is the number in the list below:

1. Scientific Requirements Specification for ATSR-2 on ERS-2
   ER-RS-MSL-AT-2001
2. The ATSR Scientific Investigation Plan
   ER-PL-RAL-AT-0014
3. AATSR Instrument Performance Requirements
   PO-RS-GAD-AT-0002
4. AATSR Data Processing Requirements
   PO-RS-GAD-AT-0003

1.4. Definition of Terms

Thermal channels are defined as those which measure emitted thermal radiation (and which can be used to measure temperature). For the purpose of this document the thermal section of the electromagnetic spectrum is defined as having a wavelength greater than 3.0µm.

Reflection channels are defined as those which measure reflected solar radiation (and which can be used to measure land surface reflectance). For the purpose of this document the visible and Near Infra-Red (VNIR) section of the electromagnetic spectrum is defined as having a wavelength range between 0.4µm and 3.0µm, and includes the AATSR reflection channels.

The **Instantaneous Field of View** (IFOV) is the image at an instant in time of the field stop on the ground (assuming that the detector is sensitive to the whole of the image of the field stop created by the focusing optics).

The **Point Spread Function** (PSF) is the continuous image produced by an instrument observing an object of vanishingly small dimensions, but whose area-integrated intensity is finite. An object scene can be split up conceptually into a large number of adjacent impulses: the image scene will then be observed as a scene where each of the impulses is replaced by the PSF – the image-scene is the object-scene convolved with the PSF.

Pixel size is defined as the distance between adjacent samples (sampling distance).

2. BACKGROUND TO AATSR

2.1. Background to instruments and platforms

2.1.1. ATSR-1 on ERS-1

ERS-1 is ESA's first remote sensing satellite. It is carrying out an Earth Observation programme which in support of its 'pre-operational' objectives includes objectives of a more scientific nature. Launched in July 1991, ERS-1 has a design life of 2 years (and is still providing useful data in 1996).

The two active microwave instruments on ERS-1 (the Active Microwave Instrument and the Radar Altimeter) form the core payload and are procured by ESA. Their applications are primarily of a pre-operational nature.

As a result of an ESA Announcement of Opportunity (AO), the ATSR was chosen as an extra, nationally funded instrument for ERS-1. ATSR's goals are mainly scientific, and related to climate research, i.e. primarily to measure SST to new levels of accuracy (required by the World Climate Research Programme) with a spaceborne radiometer.

2.1.2. ATSR-2 on ERS-2

ERS-2 is a follow-on to ERS-1 and provides continuity of the data sets. The ATSR instrument has been enhanced by the addition of extra channels (in the visible and near-infra-red) for land surface measurements, without prejudice to the main science objective of maintaining continuity of precise sea surface temperature observations.

2.1.3. AATSR on ENVISAT-1

AATSR, to be flown on ENVISAT-1, has the objective of providing continuity of the ATSR SST data. Therefore, the primary mission goal of AATSR is to extend the data set of high accuracy global SST measurements started by ATSR-1 and -2 to a period of at least 10 years. The AATSR will have the same four infra red channels as ATSR-1 to fulfil the continuity requirements, but will also have the three extra reflection channels first introduced on ATSR-2. The reflection channels of AATSR will give global coverage at the highest radiometric resolution (this was not possible on ATSR2 because of telemetry bandwidth constraints).

2.2. ATSR series Evolution Philosophy

The concept is of an evolution in the ATSR design and capabilities through ERS-1, ERS-2 and ENVISAT-1, as more data bandwidth, mass and power become available.

The main concepts behind each instrument are:

ATSR-1 on ERS-1

- an experimental, scientific instrument.
- a single main goal of global measurement of SST to < 0.3K for climate research.
- many scientific applications, in areas which include cloud, ice, lakes, land, atmosphere and aerosol research.
- the data bandwidth is limited, so some radiometric data compression is necessary.

ATSR-2 on ERS-2

- SST measurement to provide continuity with ATSR-1.
- cloud, ice, lakes, land, atmosphere and aerosol measurements to continue.

- addition of extra scientific goals, mainly in the area of land remote sensing, but also to provide improved data for cloud and aerosol research.
- overall instrument concept is as with ATSR, with add-on features.
- the data bandwidth is limited, especially in the visible channels, so some radiometric data compression is necessary.

AATSR on ENVISAT-1

- SST measurement continues as with ATSR-1 and ATSR-2.
- improved data rates available on ENVISAT-1 provide full radiometric resolution over full swath for all channels continuously.
- to continue the climate change record of global SST initiated by ATSR1 and continued by ATSR2.

3. SCIENTIFIC REQUIREMENTS FOR SEA SURFACE TEMPERATURE MEASUREMENTS

3.1. Background to Sea Surface Temperature (SST) Measurements

Accurate SST measurement is of great importance for climate research; for example in modelling climatic phenomena such as the El Niño Southern Oscillation, in the monitoring of global warming due to the enhanced greenhouse effect, and in the investigation of ocean-atmosphere heat transfer.

The response of weather and climate to SST is the subject of growing scientific interest, due to the large quantities of energy stored in the ocean, the energy exchanges possible with the atmosphere, and the effects of any carbon dioxide induced climate change on the oceans. Predictions of the effects of anthropogenic doubling of atmospheric carbon dioxide show rises in the ocean mixed-layer temperature of up to a few Kelvins when globally-averaged. Models also show that such ocean warming is not spatially uniform, with variations in the magnitude of warming around the globe.

From the need for a global, self-consistent SST data set, it is clear that surface observations of SST from ships of opportunity and buoys are too sparse to provide adequate analyses on this scale, except in the areas of heavily travelled shipping lanes. Ships of opportunity are also prone to measurement inconsistencies, due to the different ways in which SST data are collected (e.g. hull thermistors, cooling water intakes). In addition, measurements from buoys and from ships of opportunity are of bulk temperature. This can differ by several tenths of a degree from the true 'skin' temperature of the sea surface.

3.2. SST Requirements on AATSR

Arising from the requirements for global climate observing, the main scientific objective for the ATSR series of instruments is the global measurement of SST for climate research to a level of accuracy and precision necessary for global climate change detection and measurement.

[R01/001] **The AATSR instrument and ground processing system shall be able to produce SST retrievals routinely with an absolute accuracy of better than 0.3K (1σ limit) globally when averaged over areas of 0.5° longitude by 0.5° latitude, provided that >20% of samples within each area are cloud-free, with absolute accuracies close to 0.1K to be expected under certain favourable conditions.**

[R01/002] **The AATSR instrument and ground processing system shall be able to produce SST retrievals routinely to give SST for cloud-free samples to a relative accuracy of at least 0.3K (1σ limit) for a single sample.**

For global climate change assessment, there is the need for global SST dataset to be long-term, extending over many years and self-consistent. It is also important to note that not only are global historical SST fields an important boundary condition on Atmospheric Global Circulation Models, but they can also be used for validation of model outputs (for example, SSTs are a predicted variable for ocean-atmosphere coupled General Circulation Models)

[R01/003] **For climate change detection, the data from ATSR-1, ATSR-2 and AATSR shall be processed consistently to form a global SST historical dataset, which shall be archived and made readily available to the scientific research community.**

[R01/004] **AATSR shall be designed to provide maximum degree of continuity with previous ATSR type instruments, to assist in providing continuity of SST data.**

To be of use in climate research, the AATSR SST data must be quality assessed and validated (e.g. shipborne radiometric sea truth), both during instrument commissioning and routinely (e.g. to cope with anomalous atmospheric conditions, such as volcanic ash injections).

Instrument drift must not obscure any climate drift. For a warming trend of 0.25K per decade and an SST data set spanning at least 10-15 years, a stability of 0.1K per decade is needed to be able to detect the change with any confidence.

For AATSR products to be blended with existing bulk SST records, the relationship between the AATSR SST (skin) products and bulk temperatures must be characterised and understood.

[R01/005] **The AATSR SST products shall be quality assessed to determine the accuracy of the retrieval from radiance measurements to physical SST.**

[R01/043] **Any drift in AATSR must be characterised to better than 0.1K per decade. This must be achieved through a combination of validation, cross calibration with other instruments and intrinsic stability of the AATSR instrument. An instrument stability of 0.1K during the mission is required.**

[R01/044] **A scheme to relate skin and bulk SST shall be made available. This could be achieved for example through the development of higher level products which estimate from various data sources (including AATSR) the difference between the bulk and the skin temperature.**

In order to meet the overall accuracy specification defined in requirements [R01/001] and [R01/002], a number of further scientific requirements which contribute to this are defined in the following sub-sections.

3.2.1. Primary sensing wavelengths for SST retrieval

In order to maximise the sensitivity of the radiometric measurements which have to be made by AATSR, reference must be made to the radiation emitted by the ocean surface. In this context, the ocean surface can be considered to be a emitter of emissivity ~0.98 at around 300K. From the Planck function, the peak in emission is around 10µm. Hence, greatest radiance sensitivity to SST will be found in this region of the Thermal Infra-red (TIR). Assessment of atmospheric absorption shows that the region between 10 and 13 µm is a suitable window region. The peak in emission is quite broad and measurements in the 3 to 5 µm window region shows very high sensitivity to small changes in SST, but reflected solar irradiance is greater than surface exitance, precluding the use of this spectral range for routine measurements of SST during the day.

[R01/006] **AATSR shall measure upwelling radiance from the sea surface and atmosphere at selected wavelengths in the thermal window regions. From these measurements, SST will be determined.**

3.2.2. Atmospheric Correction for SST

Atmospheric correction of the remotely sensed upwelling radiances is a subject of great importance. From the overall global SST accuracy requirement, the contribution of atmospheric absorption and emission on the upwelling radiances must be accurately known. Thermal window regions which minimise the effects of atmospheric absorption and emission are well known. It is known that differential measurements of upwelling radiances in two closely spaced thermal channels will allow an accurate assessment of atmospheric effects, if the atmospheric effects differ between the two channels. Further improvements to atmospheric correction can therefore be made from views of the same ocean surface through at least two different atmospheric path lengths.

[R01/007] **AATSR shall provide corrections for the effects of the atmosphere (gas molecules, water vapour, aerosols, dust) upon the SST retrievals by use of multiple thermal channels.**

[R01/008] **AATSR shall be able to provide additional corrections for the effects of the atmosphere upon the SST retrievals by use of multiple views of the same patch of ocean.**

[R01/009] **The channels shall be chosen in order to build on previous atmospheric correction research carried out with AVHRR and other sensor SST retrievals.**

[R01/010] **The AATSR processing system shall be sufficiently flexible to adapt to evolutionary changes, for example incorporating ancillary data (eg from a microwave radiometer) to improve the knowledge of atmospheric effects.**

[R01/011] *deleted: requirement included in [R01/005]*

3.2.3. Cloud clearing requirements

A key condition to meet the overall SST accuracy requirements is that of effective cloud clearing. Accepted ways are to look at a reflection channel during the daytime (when cloud will be bright compared to the sea surface), or, at night, by looking for large differences between retrieved SSTs from different channel combinations (split window/dual window, for example).

[R01/012] **AATSR shall have one or more reflection channels, to assist in daytime cloud discrimination.**

3.2.4. Sampling distance and IFOV requirements

With the thermal channels, SST can only be retrieved for cloud-free regions. These must be correctly identified to avoid assigning biased SST, particularly for sub-sample clouds. The overall SST accuracy requirement states that 20% of samples need to be cloud-free over a 0.5 degree by 0.5 degree cell. For adequate noise reduction through averaging of individual sample values, a minimum of 500 samples should be cloud free. In the limiting scenario of 80% cloud cover this requires a total of 2500 samples which for a 50 by 50 km cell gives a sample size of 1 km. Research with previous sensors has also shown that 1 km is a reasonable compromise between data volume and spatial resolution for SST feature mapping.

[R01/013] **The AATSR sampling distance shall be 1 km at the nadir sub-satellite point in both the along track and across track directions**

There is a scientific requirement for co-alignment of the individual channel's IFOVs and samples. Experience has shown that this is necessary if the cloud clearing algorithms are to work successfully at the edges of cloud-banks. It is estimated that up to 0.1 sample misalignment is acceptable for the cloud clearing procedures for the SST derivation.

[R01/014] **The individual AATSR channel IFOVs and samples shall be co-aligned to 0.1 of the sampling distance.**

3.2.5. Radiometric Range Requirements

Since it is intended to measure SST globally, it is necessary for the AATSR instrument and processing system to be able to measure SST with accuracy within specification or better over the full range of temperatures which are likely to be found globally.

[R01/015] **The AATSR system shall be able to measure SST with accuracy within specification or better over the full global expected SST range.**

3.2.6. Revisit/Swath Requirements

In order to be able to provide regular global SST coverage, there must be a reasonable maximum time for re-imaging a given area of the globe. From this, the revisit time and swath width can be assessed. An area of the ocean surface should be revisited at least 5 times over a month to be reasonably confident of cloud-free data and to provide statistics for a monthly mean global SST field. Assuming a 35 day orbit repeat cycle (from ERS), then the swath width of the AATSR must be at least 500 km. The discussion above is subject to revision, in the light of ENVISAT-1 orbital analysis. Note that the swath width must be the maximum compatible with the SST accuracy requirements.

[R01/016] **The AATSR swath width shall be at least 500 km and must be compatible with the SST accuracy requirements.**

3.2.7. Calibration and Characterisation Requirements

To retrieve SST from the AATSR detector signals, the spectral response and IFOV of the channels need to be measured prior to launch. In addition, to demonstrate that AATSR will meet the scientific requirements for SST measurement, a pre-launch end-to-end radiometric calibration of the instrument is necessary.

[R01/017] **AATSR shall undergo a pre-launch calibration of the thermal channels to ensure that the SST measurement requirements can be met and that the characteristics of the instrument are understood over a wide and representative range of operating conditions.**

[R01/018] **Pre-launch calibration of AATSR's thermal channels shall include IFOV and spectral response measurements and end-to-end radiometric calibration.**

To ensure long term stability of AATSR SST measurements over the mission lifetime, some form of in-orbit radiometric calibration is necessary, in order to correct for instrument ageing effects on the radiometric measurements. This should be designed to provide known sources of radiance to the radiometer (including all optics) at roughly the ends of the SST scale.

[R01/019] **AATSR shall incorporate an in-orbit thermal channel radiometric calibration system. This will provide a continuos in-orbit reference which, together with laboratory measurements during the mission, will ensure accurate compensation for instrument drifts throughout the mission lifetime.**

3.2.8. Product Requirements

In order to meet the SST requirements [R01/001] and [R01/002], two different types of SST product are necessary. A spatially averaged SST product is necessary to meet the requirements of global modelling and for investigations of large-scale processes, whereas for many other applications such as investigations of data quality, a high spatial resolution SST product is necessary. Brightness temperature products will be required at both resolutions for applications such as inclusion in direct assimilation schemes and identification of cloudy and land filled samples.

[R01/051] **The AATSR instrument and data processing system shall produce high resolution (minimum sampling distance 1 km) collocated and geometrically corrected images of brightness temperature over sea.**

[R01/052] **The AATSR instrument and data processing system shall produce global spatially-averaged brightness temperature images (in either 0.5° latitude by 0.5° longitude or 50km by 50km grid cells-** ***TBC*****).**

[R01/020] **The AATSR processing system shall provide global spatially-averaged SST images (in either 0.5° latitude by 0.5° longitude or 50km by 50km grid cells-** ***TBC*****) using raw AATSR data and any necessary auxiliary information.**

[R01/021] **The AATSR processing system shall provide high resolution (minimum sampling distance 1 km) SST images using raw AATSR data and any necessary auxiliary information.**

3.2.9. Weather forecasting requirements for SST

One important application of AATSR SST retrievals is as input to weather forecast models. A demonstration project, where spatially averaged SST has been routinely generated in *Near* Real Time (NRT), has already explored the usefulness of providing NRT data to weather forecasting agencies.

[R01/022] **AATSR SST data shall be made available in a timely manner as with other ENVISAT-1 NRT products.**

3.2.10. Validation requirements

It is essential to verify that both the high resolution and spatially averaged sea surface temperature products are made to the required accuracy. The products must be validated in a representative range of conditions, sites and seasons. To ensure consistency and repeatability, a well-defined validation protocol must be followed by all validation campaigns.

[R01/053] **The AATSR SST products shall be validated to determine the accuracy of the retrieval of the SST**

[R01/068] **To determine the stability of the AATSR measuring system, including the geophysical elements, the AATSR SST products shall be validated over the duration of the mission**

[R01/054] **AATSR SST products shall be validated following a defined protocol.**

[R01/055] **AATSR SST products shall be validated over a representative range of atmospheric conditions**

[R01/056] **AATSR SST products shall be validated over a representative range of sea surface temperatures**

[R01/057] **AATSR SST products shall be validated over a representative range of seasons**

[R01/058] **AATSR SST products shall be validated over a representative range of locations**

[R01/059] **AATSR SST products shall be validated in regions where warming/cooling is predicted to be most significant**

4. SCIENTIFIC REQUIREMENTS FOR LAND REMOTE SENSING

4.1. Introduction

Pioneering studies using AVHRR data have shown that global monitoring of land, especially vegetation, at moderate resolution (i.e. ~1 to ~4 km) is of great value in studying a number of urgent global environmental problems.

In parallel, there has been a considerable amount of research, using Landsat, into the use of several reflection bands for vegetation remote sensing. This work was initially with the Multi-Spectral Scanner (MSS) instrument (with 4 reflection bands), and more recently with the Thematic Mapper (TM) instrument (having 6 reflection bands and one thermal band).

The intention with ATSR-2 and AATSR is to build on this work, essentially combining the global coverage of an AVHRR-type instrument with the improved spectral coverage of a Landsat TM-type instrument.

[R01/023] **AATSR shall carry channels which measure top of the atmosphere radiative fluxes from which vegetation quantity and quality might be estimated.**

[R01/024] **AATSR shall provide continuity of the land surface measurements started with ATSR-2.**

The ATSR-2 and AATSR's land surface remote sensing capabilities are necessarily features added to the basic ATSR instrument, and must not prejudice the primary SST measurement requirements of the ATSR series.

[R01/025] **The new reflection channels, introduced on ATSR-2, are an add-on to the basic ATSR-1 instrument which shall not compromise the SST measurements stated in requirements [R01/001] and [R01/002].**

4.2. Vegetation quantity

The reflectance spectrum of foliage shows a low reflectance (~0.05) in the visible part of the spectrum coinciding with maximum solar irradiance, at which wavelengths light is absorbed by vegetation for photosynthesis. In the near infra-red (NIR), foliage has a high reflectance (~0.5), with a very rapid transition between the red and NIR regions at ~0.75µm. This is completely different from the reflectance spectrum of the 'background material' (i.e. soil) against which the leaves are usually observed. Soil has a fairly flat spectrum (gradually rising at higher wavelengths) over the same region, though its absolute reflectance varies with soil-type and moisture (wet soil being darker than dry soil).

Hence either the ratio or difference between two spectral bands on either side of the ~0.75µm transition will give a measure of the quantity of foliage present. Those bands usually chosen are centred in the red (R) part of the spectrum at ~0.66µm and in the near-IR (NIR) at ~0.87µm.

A number of 'vegetation indices' involving these two bands have been proposed and used. To provide assessment of vegetation quantity, using these established vegetation indices, AATSR requires two reflection channels in the red and NIR spectral regions.

[R01/026] **AATSR shall have reflection channels in the red and near infra-red for assessment of vegetation quantity.**

4.3. Vegetation state (growth stage and health)

Healthy growing vegetation has a reflectance peak in the green part of the spectrum, which is indicative of the amount of chlorophyll present. Thus, the reflectance in a green spectral band is reduced for senescent, diseased or damaged foliage.

Studies using the TM green band in conjunction with the red and NIR bands show this effect. Important extra information is obtained on the growth stage (as well as indications of damage) by combining the three bands in this multi-spectral approach. For AATSR, a narrow band channel in the green spectral region is considered optimal.

[R01/027] **AATSR shall have a green channel for assessment of vegetation state.**

4.4. Leaf moisture

At wavelengths greater than 1µm, as the leaf dries out, the normally strong water absorption features disappear and the reflectance increases. Thus, the reflectance in this region gives a measure of the leaf moisture. In particular, the 1.6 µm reflectance peak provides an accurate indication of leaf water content, and research using TM has shown that the ratio of the 1.6 µm band with the 0.85µm band, can provide a good Leaf Moisture Index (LMI) or Moisture Stress Index (MSI). This Index is also widely used in airborne remote-sensing studies and a 1.6 µm band will be used on the newest versions of AVHRR, as well as for NASA Polar Platform instruments such as MODIS. The ATSR's 1.6µm band, though required for cloud-clearing for SST, is suited to this leaf moisture monitoring task, being almost coincident with the equivalent TM band.

4.5. Use of thermal bands for vegetation monitoring

One objective for the thermal bands is the improved global monitoring of burning vegetation. Basic monitoring has been carried out by AVHRR and ATSR-1, where a sample containing a fire can be identified because it saturates the thermal bands. It has been shown, however, that whether a fire is intense or smouldering determines the quantity and type of gases emitted to the atmosphere, with important implications for the carbon cycle and the enhanced greenhouse effect (since ~20% of the current carbon dioxide addition to the atmosphere is thought to be due to forest burning). The ATSR-1 thermal bands also normally saturate for a sample containing a significant forest fire.

A science objective for AATSR is to measure the radiance of exceptionally hot samples, at relatively coarse accuracy and resolution. Hence, AATSR must have a means of reducing the gain to such a level on the long-wavelength thermal channels so as not to saturate with an exceptionally hot sample.

[R01/028] **AATSR shall be able to measure the radiance of exceptionally hot samples (to an upper limit of 500°C), without prejudice to SST or other measurements.**

4.6. Radiometric requirements

The radiometric requirements are the same for each reflection channel.

4.6.1. Radiometric range requirements

The reflection channels need to be able to encompass all possible normal variations in brightness over the whole of the Earth's surface, except sunglint, without saturation.

[R01/029] **The AATSR reflection channels shall be able to measure a minimum signal of zero.**

[R01/030] **The AATSR reflection channels shall be able to measure a maximum signal which shall be derived by assuming the value at the top of the atmosphere with 100% spectral albedo of ideal Lambertian reflection**

The 100% spectral albedo value should encompass most natural levels of reflected sunlight except sunglint. It is however possible that spectral radiance values greater than this can be obtained by the addition of an atmospheric signal due to aerosol scatter, or due to non-Lambertian reflection. For example, the highest cloud target reflectances are predicted to correspond to an effective albedo of 110-120%. Conversely, it may be found during flight that 100% albedo is unrealistically high for most situations of scientific interest. Therefore, to maximise the precision of the measurements whilst retaining flexibility in the range of the instrument it is essential that the gain and offset of the reflection channels are selectable in flight.

[R01/031] **The gain and offset of the AATSR reflection channels shall be selectable in flight, in order to maximise the precision of the measurements of measured radiances and to retain flexibility in the range of the instrument.**

4.6.2. Radiometric resolution and noise requirements

For the land applications outlined above, the assessment for AATSR is that it would be desirable to measure differences in vegetation reflectance of order ~1% for ~10% vegetation cover.

This requirement cannot be confirmed, or precisely converted to a radiometric resolution requirement, without considering reflectance contributions from soil and atmosphere.

For an initial assessment, nevertheless, consider vegetation quantity. Experience with AVHRR (with 10-bit digitisation) and TM (with 8-bit digitisation) has shown that in some circumstances they are inadequate, and that a signal-to-noise ratio of at least 20 to 1 at 0.5% albedo is necessary for the red and NIR bands. Also, ignoring atmospheric contributions, and with 10% ground cover by typical leaves (reflectances red: 5%, NIR: 50%) over a typical soil (reflectances red: 20%, NIR: 30%), this noise level would, in principle, enable ~2% differences in leaf area, for constant soil reflectances, to be measured.

[R01/032] **The AATSR reflection channels shall have a signal to noise ratio of 20:1 at 0.5% spectral albedo.**

4.6.3. Radiometric Accuracy

The system shall measure top of the atmosphere radiances to an absolute accuracy of 5% over its entire range, defined in requirements [R01/29] and [R01/30]).

[R01/060] **The system shall measure top of the atmosphere radiances to an absolute accuracy of 5% over its entire range.**

4.6.4. Reflection Channel Calibration Requirements

To retrieve land parameters from the AATSR detector signals by modelling, the spectral response and IFOV of the reflection channels need to be measured prior to launch.

[R01/033] **The AATSR reflection channels shall undergo a pre-launch calibration, including IFOV and spectral response measurements.**

For long term monitoring of land parameters, it is important to have confidence in the stability of the sensing system. Thus, for the reflection channels, it is a scientific requirement that they have some form of in-orbit calibration. It is necessary to have a system which can perform both gain and offset calibration of the detector system. The thermal channel calibration sources ([R01/019]) can be used as a zero radiance calibration point for the reflection channels

[R01/034] The AATSR reflection channels shall have an in-orbit calibration for gain and offset, to provide confidence in long term measurements of land parameters and comparisons with ATSR-2 results.

4.7. Product requirements

For the science goals described above, a number of products are required to be produced by the AATSR data processing system. High resolution, collocated and geometrically corrected thermal and reflectance images are needed from which high resolution and spatially averaged land surface temperature and vegetation state products can be produced.

[R01/035] The AATSR instrument and data processing system shall produce high resolution collocated and geometrically corrected images of reflected radiation over land.

[R01/045] The AATSR instrument and processing system shall provide high resolution (minimum sampling distance 1km) land surface temperature images using raw AATSR data and any auxiliary information

[R01/046] The AATSR instrument and processing system shall provide global spatially-averaged land surface temperature images using raw AATSR data and any auxiliary information.

[R01/047] The AATSR instrument and processing system shall provide high resolution vegetation products (TBD) using raw AATSR data and any auxiliary information

[R01/048] The AATSR instrument and processing system shall provide global spatially averaged vegetation products (TBD) using raw AATSR data and any auxiliary information

4.7.1. Validation requirements

It is essential to verify that the AATSR data obtained over land is made to the required accuracy. The data must be validated in a representative range of conditions, sites and seasons. To ensure consistency and repeatability, a well-defined validation protocol must be followed by all validation campaigns.

[R01/060] The AATSR data obtained over land shall be validated to determine the accuracy of the retrieval.

[R01/069] To determine the stability of the measuring system, including the geophysical elements, the AATSR data obtained over land shall be validated over the duration of the mission.

[R01/061] The AATSR data obtained over land shall be validated following a defined protocol.

[R01/062] The AATSR data obtained over land shall be validated over a representative range of atmospheric conditions.

[R01/063] The AATSR data obtained over land shall be validated over a representative range of land surface temperatures.

[R01/064] The AATSR data obtained over land shall be validated over a representative range of seasons.

[R01/065] **The AATSR data obtained over land shall be validated over a representative range of locations.**

[R01/066] **The AATSR data obtained over land shall be validated over a representative range of land cover.**

[R01/067] **The AATSR data obtained over land shall be validated over a representative range of sun-surface-sensor viewing geometries.**

5. SCIENTIFIC REQUIREMENTS FOR OTHER RESEARCH

5.1. Cloud and atmospheric measurements

ATSR-1 is a research tool for cloud type identification and cloud top temperature measurement. The infrared radiometer's multi-channel and two-view features are a powerful combination for cloud, aerosol and atmospheric investigations. In particular, the two-views of ATSR provide a stereo viewing capability which is being used to provide assessments of cloud height.

Though the reflection channels of AATSR are required for land measurement, they have a number of applications which will enhance cloud and atmospheric monitoring capability over ATSR-1. The NIR band will provide additional information, which is complementary to the 1.6µm band, for ice/water cloud discrimination, and for sizing cloud droplets; possible relationships to precipitation will also be investigated during the AATSR programme.

Estimation of atmospheric aerosol loadings will be of use in quality assessing SST retrievals, which can be significantly affected during, for example, atmospheric contamination due to volcanic ash injections. Already, the 1.6µm channel on ATSR-1 is being used to estimate aerosol optical depths over oceans. This work will be extended using the additional reflection data in order to measure aerosol optical depths, particle size distributions, aerosol mass loading and to monitor transport and formation. As GCMs become increasingly sophisticated, the need for global, quality assessed and validated aerosol data as input is being recognised.

Since a large part of the atmospheric attenuation/emission of thermal radiation in the atmospheric window regions used to remotely sense SST is caused by highly variable water vapour, it is possible to estimate the content of the atmospheric column from ATSR data. Research is being actively pursued in the UK and in Australia. The accurate and precise measurement of atmospheric water vapour is potentially extremely important for climate research, as water vapour is the major greenhouse gas, and is also involved in atmospheric processes such as cloud formation, precipitation and evaporation.

[R01/036] **AATSR global high resolution and spatially averaged data (GBTR, GST and AST data products) shall be made available to the atmospheric research community.**

[R01/049] **Over cloud, the AATSR instrument shall provide high resolution (minimum sampling distance 1km) cloud top temperature (and cloud top height, TBC) images using raw ATSR data and any auxiliary information.**

[R01/050] **The AATSR processing system shall provide aerosol optical depth, size distribution, mass and number concentration (TBC).**

5.2. Other measurements

A number of other uses for ATSR thermal data have been proposed, including day/night temperature difference measurements for geological or soil moisture studies, geothermal heat studies, annual lake surface temperature cycles and cross-calibration of other sensors. When used synergistically with other sensors, many other potential uses such as snow cover monitoring, monitoring lake volume changes, monitoring variations in the annual sea ice growth and decay, location of boundaries and features of the Antarctic ice sheet, wetland monitoring and feature mapping for radar altimetry over land and ice have been suggested.

[R01/041] **Flexibility in adding new products to the AATSR processing system shall be necessary for long term exploitation of the data set.**

Variations in the annual sea ice growth and decay cycles in polar regions are a strong indicator of climatic change, particularly as modelling shows anthropogenic climate change to be pronounced in polar regions. In addition, the sea ice extent itself affects the climate (due to the difference in albedo of the sea ice in comparison with the ocean surface, and the thermal insulation), and so is an important parameter for climate modellers and for studies of ice-ocean-atmosphere exchanges.

ATSR-1 is being used, together with other ERS-1 sensors (i.e. RA, SAR) to study the Antarctic and Arctic sea ice boundary, and to investigate ice surface temperatures. The discriminatory power of the 1.6µm channel for cloud and ice/snow is a topic of research interest. Initial case studies are expected to lead on to systematic monitoring of both polar regions, with enhancements in cloud/ice discrimination with the reflection channels on board later ATSRs.

[R01/039] **For sea ice measurements, AATSR brightness temperature and reflectance images over sea ice shall be provided by the instrument and processing system.**

[R01/037, R01/038, R01/040] *deleted (no longer relevant)*

5.3. Specialist Requirements

Level 0 and ungridded level 1b products will not be systematically distributed to users. However, for certain specialist applications these products may be required. Level 0 data (counts) may be required for management of the instrument and for the detection of hardware and software anomalies in the reference processing system. UBTR may be required by users who wish to carry out their own co-registration of the forward and nadir views over land.

[R01/042] **For certain specialist scientific applications or for calibration purposes, counts data, or ungridded level 1b data may be required. Such data should be obtained by special agreement with ESA or DoE**

6. GLOSSARY

AATSR	Advanced Along-Track Scanning Radiometer for ENVISAT-1
AMI	Active Microwave Instrument
ATSR	Along-Track Scanning Radiometer (generic term, and sometimes used to refer to the instrument for ERS-1)
ATSR-1	Along-Track Scanning Radiometer-1 (the ATSR for ERS-1)
ATSR-2	Along-Track Scanning Radiometer-2 (the ATSR for ERS-2)
AVHRR	Advanced Very High Resolution Radiometer
BT	Brightness Temperature
Co-I	Co-investigator
ERS-1	ESA's European Remote-sensing Satellite 1
ERS-2	ESA's European Remote-sensing Satellite 2
ESA	European Space Agency
GAC	Global Area Coverage (AVHRR)
GCM	General Circulation Model
GOME	Global Ozone Monitoring Experiment
IR	Infrared
IFOV	Instantaneous Field of View
LAC	Local Area Coverage (AVHRR)
LMI	Leaf Moisture Index
MODIS	Moderate resolution Imaging Spectroradiometer
MSI	Moisture Stress Index
MSS	Multi Spectral Scanner (Landsat)
MWR	Microwave Radiometer
NASA	US National Aeronautics and Space Administration
NERC	Natural Environment Research Council
NDVI	Normalised Difference Vegetation Index
NIR	Near Infra-red
NOAA	US National Atmosphere and Ocean Administration
NRT	Near Real Time
PAR	Photosynthetically Active Radiation
PI	Principal Investigator
PPF	Polar Platform
RA	Radar Altimeter
SADIST	Synthesis of ATSR Data into Sea Surface Temperature
SAR	Synthetic Aperture Radar (part of AMI)
S/N	Signal-to-Noise
SST	Sea Surface Temperature
TBC	To Be Confirmed
TBD	To Be Determined
TIR	Thermal Infrared
TM	Thematic Mapper
VI	Vegetation Index

VNIR	Visible/Near-Infrared