AATSR
Validation Implementation Plan

Version 5: Scientific Exploitation

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1 INTRODUCTION

The Advanced Along-Track Scanning Radiometer (AATSR) was launched on Envisat in March 2002. The AATSR instrument is designed to make precise and accurate global Sea-Surface Temperature (SST) measurements, which when added to the large data set collected from its predecessors ATSR-1 and ATSR-2, will provide a long term record of SST data (> 15 years) that can be used for independent monitoring of climate change. Validation of AATSR is defined as the assessment by independent means of the quality of AATSR data products. Over sea, the primary product of AATSR is SST. Over land, because of the developmental nature of potential land products, namely Land Surface Temperature (LST) and Normalised Difference Vegetation Index (NDVI), the primary product for validation purposes is considered to be top-of-atmosphere (TOA) visible and near infrared reflectances and thermal brightness temperatures.

1.1 Scope of this document

The AATSR validation documentation is made up of three elements:

1. **AATSR validation principles and definitions** [AD1]. This document (part 1 of the validation documentation set) gives an overview of the AATSR validation programme and sets out the principles behind it.
2. **The AATSR measurement protocol** [AD2]. This document (part 2 of the validation documentation set) discusses the measurements needed for validation, and recommends the instrumentation and procedures that should be used.
3. **The Validation Implementation Plan** (VIP). This document (part 3 of the validation documentation set) describes the requirement and strategy for obtaining validation data at various stages of the AATSR mission. Several versions of the VIP exist, covering:
   a. *The initial validation of AATSR*. Detailed activities that were carried out up to and including the MAVT workshop MERIS and AATSR validation team (MAVT) validation workshop, which was held in October 2003, are described in versions 1 to 3 of the VIP [AD3]. A key outcome of this workshop was the recommendation that AATSR data should be unconditionally released to all users.
   b. *Validation during early data exploitation*. Validation activities during the first Envisat data exploitation phase are described in version 4 of the VIP [AD4]. These activities covered the first Envisat Symposium, in September 2004 and conclude with the first AATSR/MERIS user workshop in September 2005.
   c. *Validation during ongoing exploitation*. This document is version 5 of the VIP and describes validation activities to support the ongoing scientific exploitation of AATSR data.

All of the documents have been approved by the AATSR Science Advisory Group (SAG).

1.2 Current status of AATSR validation

The AATSR scientific requirements require that AATSR SST values achieve an absolute accuracy of better than ±0.5 K, with ±0.3 K (one sigma) adopted by the project as the target accuracy. The validation activities undertaken to date have shown that the AATSR instrument meets the specification at night for D3 retrievals, with larger errors observed during the day for D2 retrievals.

In summary:

- AATSR spatially averaged D3 SST values have a warm global bias of + 0.17 K from global validation against in situ buoy data.

  Some limited regional analysis (comparing only the Caribbean and the Bay of Biscay) has shown the warm bias to be towards the tropics (a bias of + 0.24 K is observed in the Caribbean region), with little if any bias seen towards high latitudes (a bias of + 0.03 K is observed in the region of the Bay of Biscay).

- AATSR gridded D3 SST values have a consistent warm bias of + 0.11 K at the tropics (from validation against M-AERI in the Caribbean), with variable warm bias of + 0.04 K to + 0.20 K seen towards high latitudes (from validation against ISAR in the Bay of Biscay). The variable bias from the ISAR validation conflicts with the consistent bias observed from the buoy validation results in this region.

- There is a strong latitude dependent difference between night time D2 and D3 retrievals indicating a latitude dependent bias in all day time D2 SST retrievals.

  The D2/D3 bias has both a latitude dependent part, varying between -0.1 K and +0.1 K, and a global offset of approximately -0.2 K. The latitude dependent part is a consequence of using global coefficients and can be empirically corrected, whereas the global offset is a consequence of the spectroscopic parameters used to produce the coefficients and can be reduced to almost 0.0 K by using updated SST coefficients.

- The difference between the dual-channel and nadir only retrieval (D-N) can be used to identify aerosol or cloud contaminated gridded SST values in the Caribbean.

From these results, three important conclusions can be drawn:

- The current validation strategy is extremely effective, showing
  - The benefits of acquiring long term validation data, allowing statistically significant biases and standard deviations to be calculated, resulting in improved accuracy of SST values.
  - The benefits of having in situ data from both radiometers and buoys that covers a range of global SST values.
  - That long-term validation with frequent sampling is essential to future data exploitation, particularly in the establishment of climate trends in SST at both global and regional scales.
- The pre-flight SST coefficients currently used in the operational processor are not optimal
- The spatially averaged SST values in the tropics (Caribbean) are contaminated (bias of +0.17 K compared to + 0.11 K for gridded SST). The source of the contamination is most likely undetected aerosol or cloud.

These conclusions form the basis of the ongoing validation activities proposed in this document to support scientific exploitation and show that the ATSR series of instruments continues to be the world leader in delivering accurate measurements of SST, which is a key climate variable.

2 SCIENTIFIC PRIORITIES FOR AATSR

The scientific priorities for AATSR are detailed in several documents, notably the AATSR Scientific Requirements [AD5] and the AATSR Science Exploitation Plan [AD6]. The top priority is to determine the ultimate accuracy of AATSR SST, globally and regionally, for use in monitoring climate change.

The AATSR Scientific Requirements [AD5] specify that AATSR's SST values achieve an absolute accuracy of better than ±0.5 K, with ±0.3 K (one sigma) adopted by the project as the target accuracy. This level of accuracy would allow reasonably accurate calculations of ocean-atmosphere heat transfer and reasonably accurate tracking of major SST anomalies such as El Niño, which are typically of 3 to 4 K in magnitude.

In monitoring climate change from long time-series of data, the main scientific problem is that of discriminating between natural variability and trends. A number of analytic techniques are available to facilitate the characterisation of natural variability, thus a major area of research using AATSR data will be that of variability of the ocean-atmosphere system, including manifestations of large-scale SST anomalies such as El Niño, which can perturb a global time-series. Overall, the scientific priority must be to generate and examine time-series of (A)ATSR in order to quantify and distinguish between natural variability and trends in the (A)ATSR record of global SST. New AATSR products, such as LST, NDVI, clouds or aerosols, represent key indicators of the climate system that could be fully incorporated into future climate prediction models.

Therefore, the central aims of an ongoing validation programme are to:

1. Monitor instrument drift in order to be able to determine global trends of sea surface temperature over time with as much confidence as possible (0.1 K per decade knowledge of instrument drift required) [*Trends*]
2. Undertake validation activities with high numbers of match-ups using *in situ* radiometer, buoy and satellite data sets. [*Trends & Fingerprinting*]
3. Investigate the performance of (A)ATSR relative to other satellite sensors in order for long-term records of SST to be continuous and extendable to periods when (A)ATSR data is not available. *[Trends]*
4. Quantify the regional characteristics of AATSR SST measurement and validation data so that it will be possible to derive regional patterns of climate change and improve knowledge of their contributions to global trends, including "fingerprinting" of climate change and assessment of changes in ocean and atmospheric circulation [*Fingerprinting*]
5. Support on-going activities connected with validation of new AATSR products that are required by users investigating climate change phenomena [*New products*]

Validation results should be assessed in the context of instrument performance arising from instrument pre-flight calibration, instrument in-flight characterisation and algorithm performance.

2.1 Justification for ongoing SST validation

An important objective of AATSR is to establish continuity of the high-precision record of global sea-surface temperature (SST) initiated by the ATSR sensor in 1991 and continued from April 1995 by ATSR-2. The AATSR sensor is expected to extend the data-set for at least five years, thereby providing a 15-year data set (through June 2006) for quantitative investigation of global climate change. Two additional scientific priorities immediately emerge from this. First, there is a need to ensure that the data from all three instruments are processed in such a way to achieve the highest levels of possible accuracy. This will be achieved through the Defra/NERC data archiving project led by RAL and the through the Defra/MoD/NERC knowledge transfer project (led by Chris Merchant from the University of Edinburgh). Secondly, there is a need to ensure that critical long-term stability and accuracy of the data-products are achieved through the validation programme.

The object of validation is to ensure that the geophysical data-products generated from AATSR data meet the accuracy specified in the AATSR Scientific Requirements [AD5] and, as a secondary objective, to determine the ultimate accuracy of AATSR under favourable geophysical conditions. Whereas in a simple case, validation is a systematic and mechanistic procedure of low scientific significance, on account of the great complexity of the ocean-atmosphere system a carefully targeted validation programme is essential to achieving the scientific objectives of the (A)ATSR mission. Moreover, the task of quantifying global change makes high demands on the accuracy and stability of the measuring system. In the case of a sensor such as AATSR, the validation programme is therefore an intrinsic element of the scientific exploitation programme that can help to rectify shortcomings in the data retrieval schemes by obtaining more information about, and achieving a better understanding of, the prevailing geophysical conditions.

2.1.1 Long term trend analysis

The requirements for the accurate detection of trends in the SST fields are stringent, raising a number of questions concerning the consistency of the data that must be addressed by the validation programme. First, there is a requirement for great stability and freedom from drift. A paper by Allen et al [RD1] showed that given the expectations for anthropogenic changes in average global SST, an instrument drift better than 0.1 K per decade is desirable for the most efficient detection of global change. This is at the limit of what can be meaningfully measured. Therefore there is a need for regular monitoring and assessment of AATSR’s SST accuracy, to the highest level of precision. Secondly, although AATSR is generally meeting the scientific requirements, it is also the case that, within the specified accuracy of 0.3 K, there are variations of accuracy from region to region. Regions that analyses have shown to be difficult include the tropical and southern Atlantic and northern Indian oceans, where there are often high concentrations of low altitude aerosols, the tropics in general where there are heavy loads of water vapour and the Southern Ocean where correlative data are extremely sparse.

2.1.2 Regional fingerprinting

Change in global SST is not only detected by monitoring global averages, it can also be detected, perhaps more rapidly than is the case with global averages, by inspecting patterns such as gradients across ocean basins or differences between ocean basins. Such techniques demand high accuracy and precision, such as only AATSR has the potential to achieve, of the order of 0.1 to 0.2 K. It is crucial to the fingerprinting approach that not only does AATSR achieve this level of accuracy, but that it does so consistently across the entire principal regions of the global oceans. For this reason, an on-going validation programme for AATSR is needed not only to monitor for drift but also to carry out targeted campaigns using autonomous systems and occasional high-precision ‘point’ samples.

For SST to be used as an indicator of climate change, it is important that regional ocean processes that have a strong SST signature are well understood. In particular the natural variability associated with such processes needs to be quantified. Major processes with the potential to perturb the global

SST signature include El Niño, the Somali upwelling, the Gulf Stream and the Kuroshio and Agoulhas currents. Research into the behaviour of such phenomena, particularly to quantify their intensity and geographical extent, should therefore receive a high priority.

Of high scientific interest is the relationship between global SST and heat content of the oceans. In particular, as the oceans warm, is it appropriate to assume that the relationship between SST and heat content remains constant? Intuitively, increased heat input to the oceans should lead to increased vertical mixing and a changed relationship between SST and heat content. Research in this area is therefore important for understanding climate change and should receive a high priority.

2.2 Validation of other AATSR products

The AATSR instrument is capable of producing geophysical parameters other than SST, related in particular to land processes (LST, albedo and NDVI) and cloud/aerosols.

2.2.1 Land Processes

As land constitutes only about one-fifth of the global surface and the heat capacity of land masses is significantly lower than that of the oceans, the properties of the land surfaces have, understandably, tended to receive less attention when investigating global climatic processes. However, the large inhomogeneity of land surfaces, notably their albedos, temperatures and transpiration properties means that, as climate models become more and more precise, there will be a great need for better information about the radiative properties of land surfaces. The AATSR can provide high quality data on LST, and on the reflective visible and emitted infrared properties of the land surface. It can also produce a state-of-the-art NDVI product that will provide information on vegetation dynamics.

The LST product has now become an operational product and an initial product validation exercise is being carried out at Leicester through funding provided by ESA. The results of the work so far are extremely encouraging with good validation results, even over heterogeneous sites.

2.2.2 Clouds and Aerosols

Clouds and aerosols are an important consideration in AATSR retrievals of SST, with consequent requirements for cloud masking and for the correction of aerosol/thin cloud contributions to the observed brightness temperatures. Understanding these effects is therefore important for achieving accurate SST retrievals.

The climatic importance of clouds and aerosols in moderating or amplifying radiative forcing is generally accepted. It is also generally accepted that our knowledge of cloud dynamic and radiative properties falls well short of that required by modern climate analyses and prediction schemes. However, both clouds and aerosols feature strongly in AATSR data. Once the immediate priority of identifying the presence of clouds in order to retrieve surface temperature has been satisfied there is much scope for using AATSR's multi-angle multi-wavelength viewing geometry to characterise and investigate the properties of clouds.

The sources of aerosols are diverse, ranging from large-scale natural events such as volcanic eruptions to desert storms, biomass burning and anthropogenic sources associated with industrial pollution and agriculture. The AATSR, on account of its unique dual angle viewing geometry, is especially sensitive to atmospheric aerosol and there is great potential for using AATSR data, generally in combination with data from other sources, to examine and quantify the radiative properties of atmospheric aerosols.

3 THE AATSR INSTRUMENT

A description of the unique functionality of the AATSR instrument can be found in [RD2]. The data collected from the instrument is processed as part of the Envisat ground segment to Level 1b (calibrated, geo-located radiances) and Level 2 (geophysical products).

3.1 Calibration

AATSR is a self-calibrating instrument. It has an on-board calibration system, which involves the use of two specially designed and highly stable blackbody reference targets (for the thermal channels), and a diffusely reflecting target that is illuminated once per orbit (for the visible and NIR channels). The instrument calibration was verified in ground tests. A number of activities were carried out post-launch to check and characterise the AATSR sensor. These are described in detail in the AATSR Commissioning Report [AD7]. The AATSR commissioning phase was completed on 16th September 2002. Further information on instrument calibration can be found in Section 5, under vicarious validation activities.

3.2 AATSR Data Products

The data collected from the instrument is processed in the Envisat ground segment to Level 1b (calibrated, geolocated radiances) and Level 2 (geophysical products). The derived AATSR SST values are estimated from algorithms based on radiative transfer models, which perform a linear regression of SST to simulated brightness temperatures (BTs) with nominal band centres located at 3.7 µm, 11 µm and 12 µm, utilising either the nadir view alone or a combination of the nadir and forward views. For well-characterized sensors like AATSR, radiative-transfer based algorithms are now established as effective alternatives to algorithms based on empirical regression, such as those used for AVHRR. During the day the 3.7 µm channel is not used due to solar contamination and so there are four possible retrieved SST values, referred to as N2 (nadir two channel), N3 (nadir three channel), D2 (dual view two channel) and D3 (dual view three channel).

There are two operational Level 2 AATSR SST products that require validation: a 1 km gridded SST product referred to as the ATS_NR_2P product and a spatially averaged SST product (at resolutions of 17 km, 50 km, 10´ and 30´), referred to as either the ATS_AR_2P product or the ATS_MET_2P product; the ATS_MET_2P product is a reduced Level 2 product containing only 10´ resolution data for meteorological users. For continuity with its predecessors, ATSR-1 and ATSR-2, the ATS_NR_2P gridded product is also referred to as the GSST (Gridded Sea Surface Temperature) product and the ATS_AR_2P averaged produced is also referred to as the ASST (averaged Sea Surface Temperature) product. It should be noted that spatially averaged SST products are not produced by averaging the gridded SSTs, but are produced by first averaging the BTs and then doing the SST retrieval.

Both the gridded and spatially averaged SST products require validation as they are used for different scientific applications. The gridded product is used for operational NRT applications such as NWP or coastal zone monitoring; in addition, the gridded product will form the basis of future applications looking into the regional aspects of climate change, referred to as fingerprinting. The spatially averaged product will form the basis of the long term climate record.

Aside from SST, the operational AATSR products contain the measured BT/reflectance values, and both Land Surface Temperature (LST) and Normalised Difference Vegetation Index over land. A summary of the operational AATSR products and their content is given below in Table 3-1.

Product ID	Name	Description
ATS_NL__0P	Level 0 Product	• Instrument source packet data
ATS_TOA_1P	Level 1b	• Full resolution top of atmosphere BT/reflectance for all channels and both views. • Product quality data, geolocation data, solar angles and visible calibration coefficients
ATS_NR__2P	Level 2 Gridded	• Full resolution nadir-only and dual-view SST over sea • Full resolution Land Surface Temperature (LST) and Normalised Difference Vegetation Index (NDVI) over land • Product quality data, geolocation data and solar angles
ATS_AR__2P	Level 2 Spatially averaged	• Spatially averaged ocean, land and cloud parameters • Spatially averaged top of atmosphere BT/reflectance
ATS_MET_2P	Meteo Product	• SST and averaged BT for all clear sea pixels, 10 arc min cell, for Meteo users
ATS_AST_BP	Browse Product	• 3 band colour composite browse image derived from L1b product. 4 km x 4 km sampling.

Table 3-1: Summary of AATSR data products

3.3 Algorithm Verification

Detailed algorithm verification of the processors used to produce the Level 1b and Level 2 products has been performed since the launch of Envisat. The process of algorithm verification will be carried out throughout the lifetime of the AATSR instrument for long-term product assurance. Algorithm verification for AATSR is provided by Andrew Birks of the Rutherford Appleton Laboratory, under an Expert Support Laboratory (ESL) contract to ESA.

3.3.1 Methodology

Algorithm verification is distinct from instrument commissioning (as described in [AD7]). Applying to all AATSR products, specific objectives of the activity include:

- To verify that the algorithms used by the AATSR Operational Processor (OP) work correctly when presented with AATSR data
- To verify that the AATSR products are being correctly generated
- To verify, and if necessary regenerate, auxiliary data files used by the AATSR OP

3.3.2 Progress to date

Most of the algorithm verification tasks were completed in the initial validation phase. The results are described in:-

- Birks, A.R., 2002, Algorithm verification for AATSR. ESA special publication 520 (written for the Envisat Calibration Review).
- Birks, A.R., 2003, Algorithm Verification for AATSR: Level 2 Verification. ESA special Publications 531 (written for the Envisat Validation Workshop).

3.3.3 Activities for Ongoing Analysis

A subset of algorithm verification tasks will be repeated regularly throughout Phase E for long term product quality monitoring. These tasks are currently being defined as part of the long term verification plan.

4 AATSR VALIDATION ORGANISATION

4.1 The MERIS and AATSR Validation Team (MAVT)

Pascal Lecomte (ESA ESRIN) is currently responsible for the Envisat validation programme. Validation of AATSR data is part of remit of the MERIS and AATSR validation team (MAVT), coordinated by Paul Snoeij (ESA ESTEC). The members of the MAVT are shown in Table 4-1.

Name	Function
Pascal Lecomte	Envisat Validation
Paul Snoeij	MAVT Coordinator
Gary Corlett ESA representative: Hannah Clarke	MAVT subgroup leader: AALV: AATSR Land Validation and AASTV: AATSR Sea Surface Temperature Validation
Philippe Goryl	MAVT subgroup leader: MCWP: Meris Clouds and Water Vapour
Mike Rast	MAVT subgroup leader: MVPAC: Meris Vegetation Product and Atmospheric Correction
Jean-Paul Huot	MAVT subgroup leader: MWPV: Meris Water Product Validation

Table 4-1: Current composition of the MAVT during the ongoing validation phase

4.2 Validation management

The AATSR validation programme involves a number of different organisations. Of primary importance are the (A)ATSR Principal Investigator, Science Advisory Group (SAG) and ESA, particularly through the MAVT and the Quality Working Group (QWG).

The AATSR Science Advisory Group (SAG) is chaired by the PI and is responsible for generating, maintaining and improving existing scientific algorithms for the generation of the scientific data products from the AATSR measurement data. The results from the validation programme feed into the maintenance and improvement process for the existing algorithms.

The AATSR Quality Working Group is the key link between the validation programme for the AATSR products and the entities implementing any required changes to the ESA operational processing scheme. The current members of the QWG are given in Table 4-2.

Organisation	**Name**	**Function**
Defra	Katherine Bass (Defra) Hugh Kelliher (Space ConneXions)	Instrument Provider
ESA	Pascal Lecomte Philipe Goryl Paul Snoeij Hannah Clarke (Vega)	Space craft operations & operational data products
University of Leicester	David Llewellyn-Jones Gary Corlett	Principal investigator & validation Scientist
RAL	Chris Mutlow Andrew Birks Jack Abolins Dave Smith	In flight performance, algorithm definition and verification & calibration

Table 4-2: Current membership of the AATSR QWG

A schematic diagram showing the key management parties involved in the validation programme is given in Figure 4-1. Interaction with users in the form of provision of information and feedback of user priorities/results is an important part of the overall scheme.

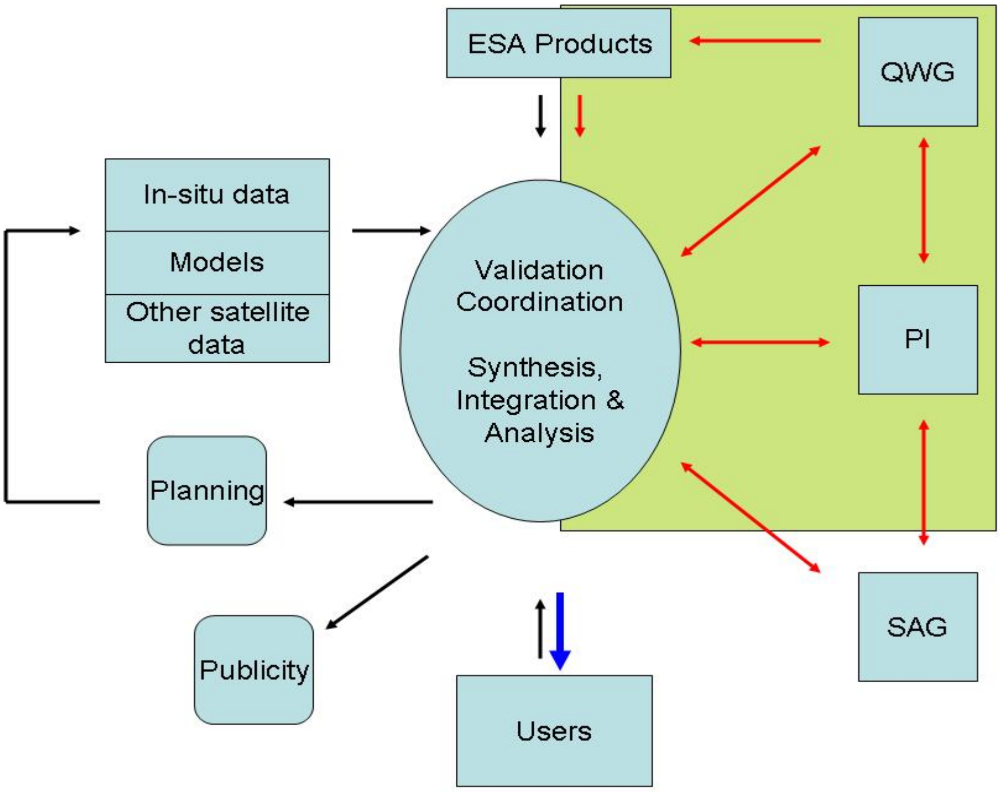

Figure 4-1: Key management parties involved in the validation of AATSR. The interfaces highlighted in red and covered by the green box represent the primary validation loop. Note that several of the links are two-way, particularly with respect to the user community for AATSR data.

The resulting operating structure for the validation programme is shown in Figure 4-2. The primary responsibility of the validation scientist is to act as a central co-ordination point for the AATSR validation programme on behalf of Defra, via its management interface of the Data Exploitation Contractor (DEC), Space ConneXions Ltd. Included in Figure 4-2 is a direct link to the Flight Operations Support (FOS) team covering the interface between mission management and validation activities. An expanded view showing the make up of the validation data providers is shown later in **Error! Reference source not found.**. Note the core SST validation activities, which are highlighted in blue in both **Error! Reference source not found.** and later in **Error! Reference source not found.**. These provide the principal activities of relevance to the main SST product of interest to Defra

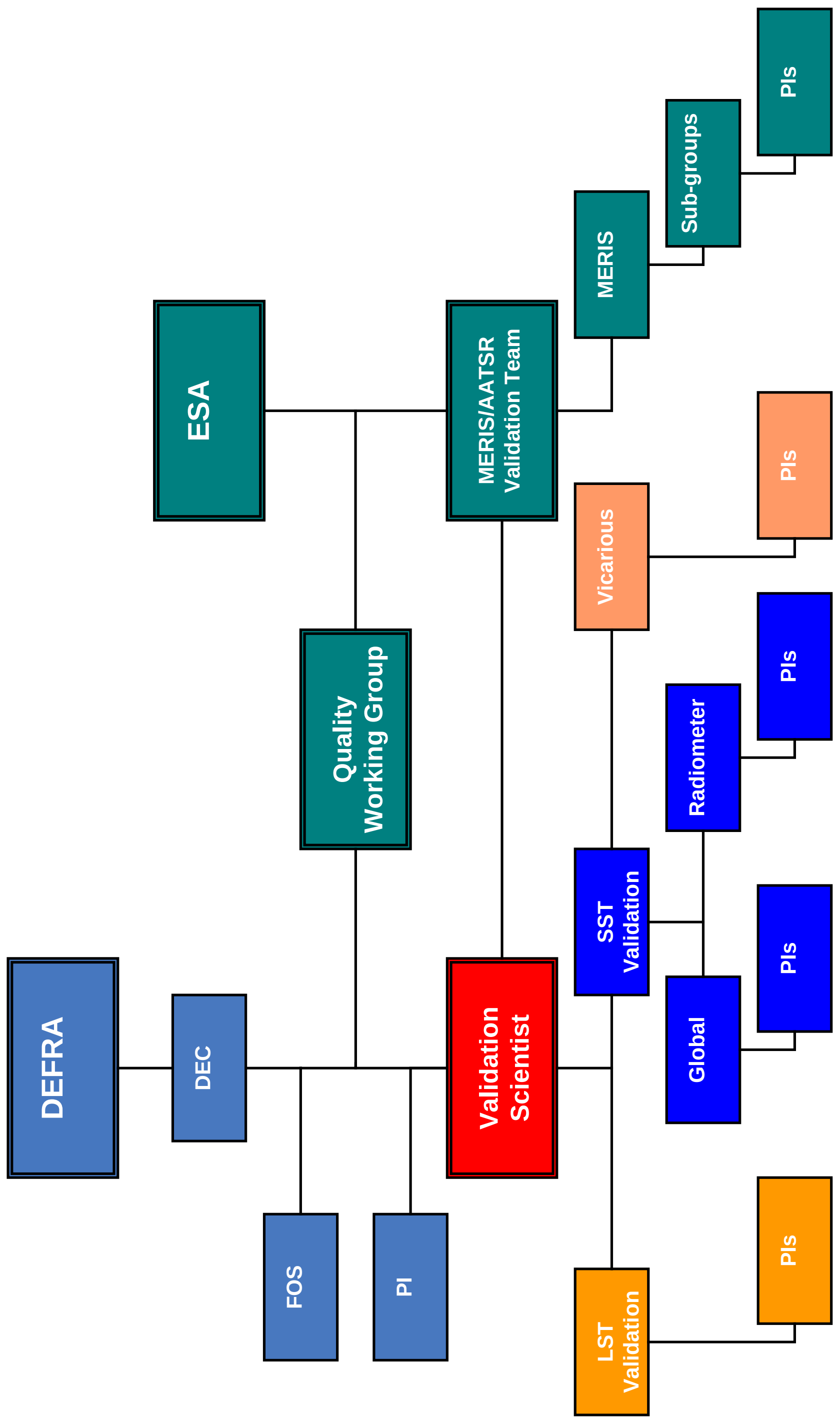

Figure 4-2: Schematic diagram showing the operating structure and communication interfaces from the validation scientist to all other relevant parties.

4.2.1 The validation scientist (VS)

The role of the VS is to provide the key link between the validation investigators and the instrument provider. The VS maintains close contact with the AATSR FOS team and provides investigators with timely information about the instrument performance and availability. The validation investigators provide their results and feedback on instrument performance to the VS who is then responsible for coordinating the results and feedback and reporting it to Defra, ESA and the PI. The VS requires regular updates (at least monthly) from the validation investigators in order to ensure that any data quality issues are highlighted and dealt with accordingly.

The AATSR VS is based at the Space Research Centre, University of Leicester, and works directly alongside the instrument PI, Professor David Llewellyn-Jones. The contacts at the University of Leicester are:

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A flow diagram, showing the decision making process, involving the PI and the QWG, is shown in Figure 4-3. Only the QWG can agree changes to the ESA operational processor.

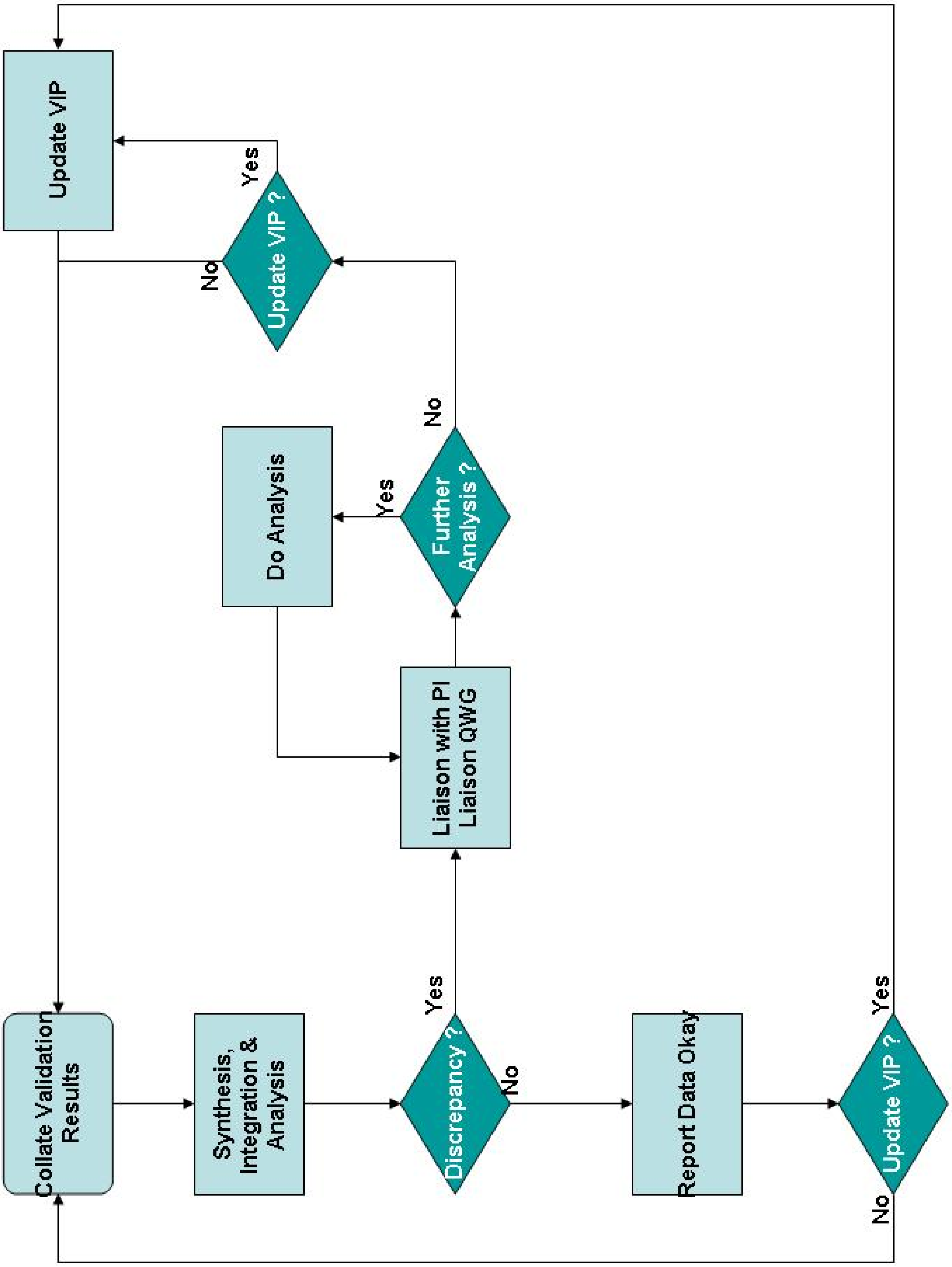

Figure 4-3: The validation decision making process

4.2.2 The validation principal investigators

The current AATSR validation team, including an indication of which validation priority each investigator addresses, is given in Table 4-3.

Product Validated	Validation Priority	Name	Institute	ESA AO No.	Status
Level 2 SST(a)	Trends Fingerprinting	Saunders, Roger O'Carroll, Anne Watts, James	Met Office	Pending	Active
Level 2 SST(a)	Trends Fingerprinting	Remedios, John Corlett, Gary Noyes, Elizabeth Minnett, Peter(c)	Uni. Leicester Uni. Miami	N/A	Active
Level 2 SST(b)	Fingerprinting	Barton, Ian	CSIRO	Pending	Active
Level 2 SST(b)	Fingerprinting	Nightingale, Tim)	RAL	552	Active
Level 2 SST(b)	Fingerprinting Trends	Robinson, Ian Donlon, Craig	NOCS Met Office	Pending	Active
Level 1b reflectance	New Products	Poulsen, Caroline	RAL	501	Active
Level 1b reflectance	Trends	Hagolle, Olivier	CNES	119	Active
Level 1b reflectance	Trends	Kerridge, Brian	RAL	Pending	New
Level 1b reflectance	Fingerprinting	Nieke, Jens	NASDA/DLR	Pending	New
Level 1b reflectance	Trends	Smith, Dave	RAL	410	Active
Level 1b IR	Trends	Hook, Simon	NASA-JPL	Pending	Active
LST	New Products	Coll, Cesar	Uni. Valencia	Pending	Active
LST	New Products	Hook, Simon	NASA-JPL	Pending	Active
LST	New Products	Prata, Fred	CSIRO	Pending	Active
LST	New Products	Sobrino, Jose	Uni. Valencia	Pending	Active
LST	New Products	Stoeve, Julienne	Colorado State	Pending	Active

(a) Level 2 spatially averaged product validation (ATS_AR__2P)
(b) Level 2 gridded SST product validation (ATS_NR__2P)
(c) Data provided by the University of Miami and analysed at the University of Leicester

Table 4-3: Composition of the AATSR validation team

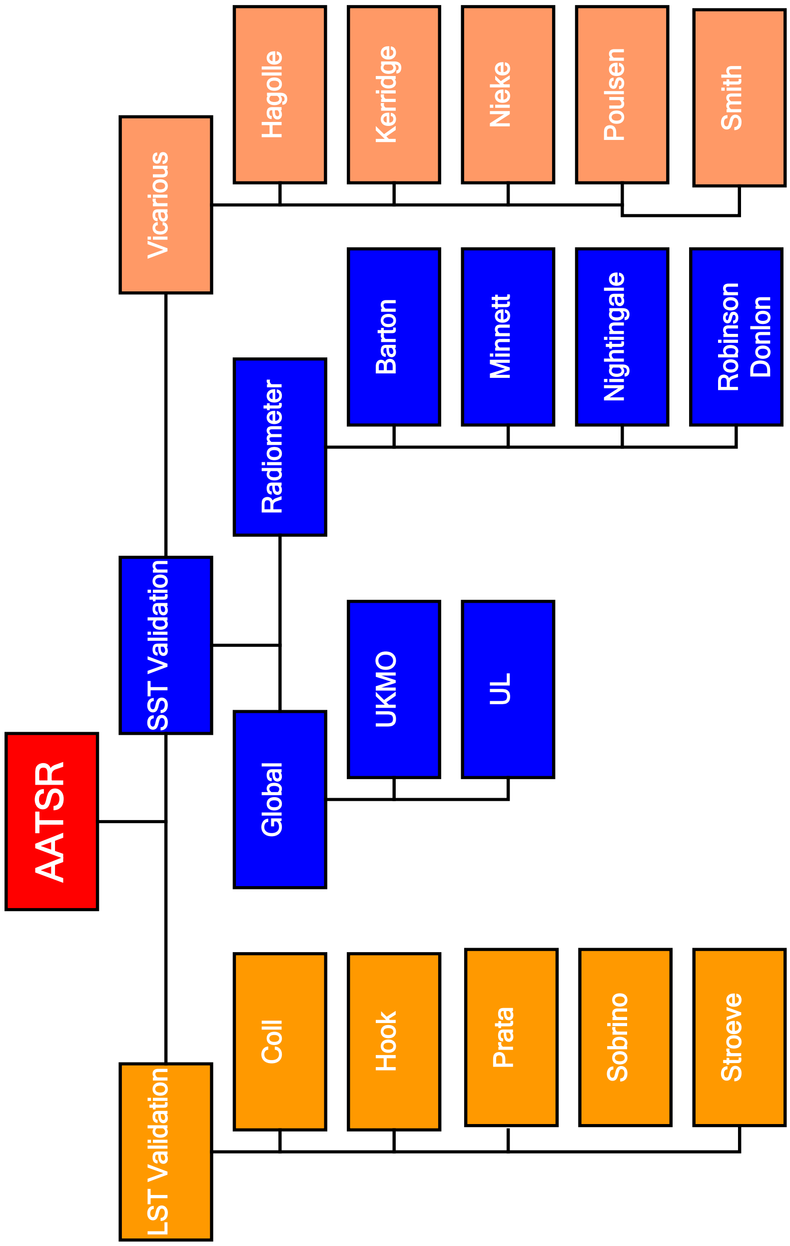

Figure 4-4: Schematic diagram detailing the make-up of the validation data providers.

Further details of the work done by individual validation team members can be found in the Appendix to the validation documentation set.

5 ONGOING VALIDATION OF AATSR SST PRODUCTS

5.1 Requirements for ongoing SST validation

The purpose of this part of the validation programme is to deliver a full assessment of the quality of the SST data products and to check that AATSR continues to generate products of the quality needed for the accurate historical record of SST data needed for climate research. The next phase of the validation activity will:

- Confirm the accuracy of AATSR data at close to 0.1 K level.
- Assess the influence of clouds and aerosol on the quality of the data.
- Feed into the issues of data continuity through comparison to a wide range of data sets.

Crucial elements of the programme include the ability:

- To build on existing ongoing measurements from buoys and in situ data sets to determine the accuracy of AATSR with statistical confidence.
- To understand the effects of clouds and aerosols on the quality of the data.
- To provide users with realistic error budgets, which allow the quality of the data sets to be included in climate analyses and operational sea surface temperature data sets.

These results will feed back into the reprocessing of the ATSR data, particularly in the establishment of a core validation data set for testing and in the identification of cloud and aerosol effects which could lead to improvements in the cloud processing schemes and in the retrieval methodology for sea surface temperature.

5.2 Strategy for ongoing SST validation

The strategy adopted for ongoing SST validation incorporates both information from satellite data and buoy analyses together with regular and campaign cruises of precision *in situ* radiometers. The overall methodology incorporates the following three aspects:

1) Regular measurements in good locations for precision validation of AATSR to improve statistics and to characterise SST accuracy and instrument drift [buoys, ISAR, M-AERI, satellites]
2) Autonomous cruises in regimes with differing geophysical characteristics but high numbers of match-ups to establish the performance of AATSR over a range of SST conditions and atmospheric humidities, including new regimes with little if any historical validation data [ISAR, M-AERI, SISTeR]
3) Well-characterised opportunistic data from regions around the globe [ARIES, DAR011, CIRIMS]

The strategy involves the following main goals:

- To continue existing validation activities that are producing useful information.
- To establish a core validation data set.
- To address priority action items concerning AATSR validation.

5.2.1 Continuation of existing SST validation activities

The benefits of long term validation data sets are clear, as they allow clear conclusions to be drawn on AATSR data accuracy through statistically significant biases and standard deviations. This is extremely important for day time validation, where the match-up process has so far been hindered by a combination of intrinsic retrieval issues (such as the D2/D3 bias) and strong diurnal heating.

Currently, we have three long term validation data sets. These are:

1. Global validation against in situ buoys performed by the Met Office

   These comparisons are performed on spatially averaged SST values by first converting the AATSR skin SST to a pseudo-bulk SST using the well-known and validated Fairall model. So far, over 32000 match-ups have been obtained. However, in certain regions (such as the Eastern Atlantic off Africa) the total number of match-ups is only a few hundred, somewhat limiting the significance of the results in these regions.

2. Regional validation against the M-AERI radiometer in the Caribbean

   These comparisons are performed on gridded SST values. So far, nearly 300 match-ups have been obtained, with only around 35% of them during the day. These match-ups are vital as they show a slightly different result to the buoy results from the Caribbean region, and without them the wrong conclusions would be drawn [that the AATSR has a warm bias of + 0.24 K in the tropics, whereas the bias is actually + 0.11 K; the difference being suspected aerosol or cloud contamination in the spatially averaged product]. Also, these match-ups provided the first indication of how the D-N difference could be used to remove aerosol or cloud contaminated data from the gridded product. Further work is needed on how this test can be used in other regions.

3. Regional validation against the ISAR radiometer in the Bay of Biscay

   These comparisons are done on the gridded product. So far, nearly 400 match-ups have been obtained, with around 40% obtained during the day. These match-ups are vital as they are in a different range of ocean temperatures than found in the Caribbean, and without them the wrong conclusions would have been drawn [that AATSR may have a cool bias at high latitudes, owing to aerosol or cloud contamination whereas the combination of the buoy results and the ISAR results shows that the contamination is most likely only in the spatially averaged product towards the tropics and that AATSR D3 retrievals have little if any bias at high latitudes in both the spatially averaged and gridded products].

The results obtained to date underline the need to continue these important validation activities.

5.2.2 Establishment of a core validation data set

The validation results collected so far provide evidence that AATSR has a warm bias in the tropics (Caribbean) and little if any bias at higher latitudes (Bay of Biscay). These results suggest that the pre-flight coefficients for the SST retrieval are not optimum and require some improvement. Once updated, it will be necessary to reprocess all of the validation match-ups collected to date, to make a qualitative assessment of the improvement of the updated coefficients. Therefore, the University of Leicester propose to create a core validation data set for AATSR that can support future coefficient development and also future algorithm development, such as a physically based retrieval approach.

5.2.3 Priority action items

Characterisation of bias and error in satellite-retrieved SSTs is essential for many applications, particularly for climate research and forecasting. Assignment of an incorrect bias will lead to errors when the data are assimilated into models and other datasets, and will result in poor user confidence in data quality. It is important to identify data with an incorrect bias in the AATSR SST record and to advise users accordingly using confidence flags. The flagged data can then be used to improve:

1. The long-term climate record, as an assessment can be performed of the effects on trend analyses that result from using the flagged data.
2. The quality control associated with incorporation into climatological datasets such as HadSST.
3. The quality control associated with assimilation into numerical weather prediction (NWP) models, such as those run by the Met Office and the Australian Bureau of Meteorology.
4. Knowledge of large aerosol particle distributions, a quantity which is also of use for NWP and climate, but which needs to be better characterised for maximum impact.

5.2.3.1 Identification of aerosol and cloud contamination

Recent results from the AATSR validation programme have revealed a potentially important source of regional and seasonal biases in the SST data derived from the ATSR series of instruments. These occur because the retrieval of SST does not account for tropospheric aerosols such as mineral dust and sea salt particles; residual cloud also causes similar effects. The biases are evident within the AATSR SST data as unusually high differences between SST retrieved using both views and those that used only the nadir view (D-N). It is possible to flag biased measurements by identifying where D-N is greater than a locally determined threshold. This methodology has been successfully applied to a limited validation study in the region of the Caribbean Sea using M-AERI data. However, the conclusions of this study cannot be extrapolated globally because of the regional variability of atmospheric conditions.

Research at the University of Leicester has identified two effects where the dual-view SST minus nadir-only SST difference (D-N) can be used to improve AATSR data. Firstly, using both *in situ* and satellite data, mineral aerosol transported over the Atlantic Ocean from the Saharan Desert to the Caribbean has been identified as affecting the SSTs recorded by AATSR. Secondly, undetected clouds are also believed to cause increased values of D-N. In summary:

- Threshold values of D-N can be defined to identify affected SST retrievals.
- Properties of cloud-affected data, such as their proximity to detected cloud, can be used to distinguish aerosol and cloud effects.
- A correction for tropospheric aerosol based on D-N can also be defined.
- The threshold values and corrections can be made available to users to provide them with the information they need to use the data correctly.

This analysis is seen as a priority action item for the ongoing validation programme, owing to the observation of a bias in the spatially averaged SST that is most likely caused by undetected aerosol or cloud. The extent of the contamination on the spatially averaged product can be studied once the effect on the gridded product is fully understood.

5.2.3.2 Development of an error budget for AATSR

As stated above, characterisation of bias and error in satellite-retrieved SSTs is essential. Indeed, following the recommendations of the GHRSST-PP, this bias and error should be known on a pixel-by-pixel basis. The identification of aerosol and cloud contamination is the first step in defining an error budget for AATSR, as it likely to be the biggest source of error. However three other tasks must also be carried out. These are:

1) Defining a set of regions, for which the different regional biases will be assigned.

   This task is important as there are obvious regional biases (such as the difference between the validation results in the Caribbean and the Bay of Biscay). Previously, regions have been assigned somewhat arbitrarily, but this should now be formalised in conjunction with the AATSR SAG and the GHRSST-PP for consistency with other sensors.

2) Defining a theoretical error budget for AATSR SST retrievals.

   This task is important to ensure that the observed biases and errors are not the result of error cancellation caused by features such as the D2 latitudinal bias.

3) Defining error budgets for the in situ data and methodology used to determine the biases.

   This task is important as the errors in the in situ data may be significantly larger than those on the AATSR retrievals. In addition, errors in the current validation methodology need to be determined.

Once these tasks have been carried out, it will then be possible to develop a full error budget for AATSR data.

5.3 Implementation for ongoing SST validation

The essential elements of the next phase of validation include:

- Global and regional analyses against buoy data and operational analysis fields over seasons and years [Trends]
- Global and regional comparisons with other satellite datasets and ECMWF analyses over seasons and years [Trends, Fingerprinting]
- Internal diagnostic validation tests of AATSR SST datasets [Trends, Fingerprinting]
- Continued deployment of ISAR and M-AERI to improve statistics of validation comparison, perform validation over a range of atmospheric conditions, and to provide long-term monitoring [Trends, Fingerprinting]
- Autonomous deployment of the SISTeR radiometer in validation poor regimes [Trends, Fingerprinting]
- Opportunistic data collection using the ARIES, DAR011 and CIRIMS on ships such as the Ronald H Brown at various regions around the globe [Fingerprinting]

Note: The descriptors [Trends] and [Fingerprinting] included at the end of each of the bullet points listed above are used to indicate which of the two SST scientific priorities, stated in Section 2, is being addressed by each of the above elements proposed for the next validation phase.

5.3.1 Continuation of existing validation activities

In the ongoing validation phase, it is envisaged that the ISAR and M-AERI radiometers operated by Prof. Robinson and Prof. Minnett, which have been operating consistently for a number of years in particular regions, will provide a continuing long term context for monitoring AATSR performance. Targeted regions of importance will be covered by operations of the SISTeR radiometer, and campaigns of the DAR011, ARIES and CIRIMS instruments.

The following activities will continue:

- The Met Office will continue the global analysis of the spatially averaged SST product by comparison with buoys networks and operational analysis fields.

  In addition, UL will continue to perform comparisons and diagnoses of global data fields with similar global fields from other sources e.g. AVHRR, MODIS, TMI and ECMWF. This analysis is directed towards providing data set continuity for periods when (A)ATSR data is not available as well as supporting specific validation of AATSR.

- UL will continue to analyse data from the M-AERI instrument on the Royal Caribbean cruise ship, as well as data from campaign cruises with other M-AERI instruments.

  Prof. Minnett has confirmed that the operation of the M-AERI onboard the Caribbean cruise liner will continue for a period covering the duration of this plan. However, the Explorer of the Seas routing will change for six months of the year from summer 2006, following a track up the Eastern seaboard of the United States. There are a number of benefits to the AATSR programme by the change in ship track, namely:

  1) It increases the absolute range of temperatures monitored by the M-AERI (to better compare to ISAR),

  2) It will provide validation data on a transect through an important Western boundary current (and its associated cloud clearing problems), and

  3) It will continue the long term data set being collected in the Caribbean for at least six months per year (during the winter months).

  At this time, Prof. Minnett is not able to confirm the opportunity cruises for which M-AERI data will be provided to UL for analysis.

- The National Oceanography Centre Southampton (NOCS) would continue to operate their ISAR onboard the Pride of Bilbao ferry, operating up and down the Bay of Biscay.

- It is hoped that autonomous measurements by the SISTeR radiometer in areas sparse of current validation data will start in 2006. The current plan is to start operations in cold waters off the coast of Norway. These activities are funded under a contract from ESA.

- Data from other radiometers such as Ian Barton's DAR011 system, the Met Research Flight Airborne Research Interferometer Evaluation System (ARIES) airborne spectrometer (this system can be considered as an airborne version of the M-AERI instrument), and the Calibrated Infrared In situ Measurement System (CIRIMS), a NOPP funded radiometer that took part in the 2001 Miami intercomparison, will be obtained on an opportunistic basis as and when data become available.

5.3.2 Establishing a core validation data set

The establishment of a core validation data set of quality assured BTs and SSTs will be undertaken at the University of Leicester. Additional quality control will be performed by visually inspecting the images to verify the AATSR operational cloud clearing, as well as other diagnostics tests. The data set will be available to all validation data users for reprocessing match-ups where required.

5.3.3 Addressing priority action items

The following two priority action areas are identified.

5.3.3.1 Identification of aerosol and cloud contamination

The University of Leicester will carry out tasks:

1. To understand better the thresholds for D-N.
2. To develop the tests to distinguish between aerosol and residual thin cloud effects on D-N.
3. To understand better how to provide a correction to the entire ATSR record.

5.3.3.2 Development of an error budget for AATSR

The two parts to this task will involve the following activities:

1. Defining a set of regions for users to apply regional corrections to the observed biases.

   So far, the AATSR project uses an arbitrarily defined set of regions that distinguish important geophysical features, such as the Gulf Stream, the Eastern Atlantic Ocean and the El Niño region in the eastern Pacific Ocean. The University of Leicester will iterate the choice of regions with users such as the Met Office, the GHRSST-PP Science team and also the AATSR SAG. Once defined, the regions will be published on the AATSR web site along with recommendations on regional corrections for users to apply.

2. Defining an error budget for AATSR.

   It is important to have an estimate of the expected errors when comparing AATSR measurement data with in situ data, not least to avoid potential cancellations of errors that may lead to incorrect conclusions as to the accuracy of AATSR data. The task will involve defining measurement error budgets for

   a) AATSR,

   b) The in situ radiometers, and

   c) Buoys.

   These errors will be defined by the University of Leicester in conjunction with the AATSR SAG, the AATSR instrument team at RAL and the in situ data providers, such as NOCS. The University of Leicester will then use these errors in the match-up process between AATSR and the in situ data to provide an error b budget for AATSR.

6 ONGOING VALIDATION OF LEVEL 1B REFLECTANCES

6.1 Overview

The level 1b thermal channels (3.7µm, 11µm and 12µm) will be validated inherently through the validation of the level 2 SST product (Section 5) and the land surface temperature product (Section 7). Validation of the visible/near infrared channels (0.55µm, 0.67µm, 0.87µm and 1.6µm) will be carried out over land and cloud. This is done in two ways, through vicarious validation and through the collection of ground measurements taken during field campaigns.

6.2 Visible and near infrared reflectance validation against stable surface locations

Several validation PI's, Dave Smith from RAL, Fred Prata from CSIRO and Olivier Hagolle from CNES, are comparing AATSR and MERIS top-of-atmosphere radiances for a range of desert regions and Greenland ice, and monitoring the long-term stability of the instruments. This will lead to a robust characterisation of the in-orbit performance of the instruments and the on-board calibrators. Using similar channels on AATSR and MERIS enables direct comparisons of the instrument calibrations to be made. The measurements will be particularly useful to check for any across track variations in the calibration of MERIS. The results will also be compared against the existing ATSR-2 data for the same scenes. Further details of the analyses are given in [RD3 and RD4].

Outputs from the work include:

- Time series of uncorrected top-of-atmosphere reflectances
- Calibration drift correction values
- Reflectances corrected for atmospheric absorption (not aerosols)
- Intercomparisons with MERIS and ATSR-2 reflectances

6.2.1 Progress to date

Full details of the work carried out to date can be found in RD3 and RD4. The results presented from the analysis by Dave Smith over both the desert and ice calibration targets show that all AATSR visible channels measure reflectances higher than those measured by ATSR-2 and that AATSR is in good agreement with the corresponding MERIS channels; combining these results shows that MERIS is also measuring significantly higher than ATSR-2

All measurements obtained so far show the following ratios:

- **R_{AATSR}/R_{ATSR-2}**
  - 0.56µm 1.132
  - 0.67µm 1.088
  - 0.56µm 1.081
- **R_{AATSR}/R_{MERIS}**
  - 0.56µm 1.041

    - 0.67µm 1.001
    - 0.56µm 1.037

- **R_{MERIS}/R_{ATSR-2}**
- 0.56µm 1.087
- 0.67µm 1.086
- 0.56µm 1.042

If MERIS and AATSR measurements were significantly different from each other as well as ATSR-2, it would suggest that the basic radiometric calibrations were incorrect. However, the results show that MERIS and AATSR calibrations appear to be in agreement with each other, but are both measuring significantly higher than ATSR-2 and a range of other satellite sensors. Errors in the pre-launch calibrations of AATSR and MERIS remain a possibility, but since both instruments were calibrated independently at different institutions, systematic errors of the same magnitude and bias would be unlikely.

6.2.2 Activities for ongoing analysis

The main activities for ongoing analysis are to continue the current work plan in order to establish why AATSR and MERIS appear to agree to each other but not to other sensors. Proposed activities include:

- Produce long term trends over desert targets to establish calibration drift.
- Compare calibration drifts of AATSR and MERIS
- Investigate 1.6µm calibration
- Work on atmospheric corrections
- Extend range of comparisons to include other instruments

In addition, other explanations for the observed differences exist that should be investigated, including:

- Errors introduced during data processing.
- Assumptions about the calibration sites.
- Assumptions about the calibrations of other sensors.
- Out of band spectral leakage.

6.2.3 Intercomparison of AATSR visible and near infrared reflectances against other satellite sensors

An evolving area of AATSR vicarious validation is the intercomparison of normalised visible and near infrared reflectance measures by AATSR with similar data from other satellite sensors including ATSR-2, MERIS, SeaWifs, GOME, SCIAMCHY, Polder, ANHRR, MISR, SPOT and VEGTATION. The work is carried out by Dave Smith from RAL, Olivier Hagolle from CNES and Brian Kerridge from RAL. Further details of the analyses are given in RD3 and RD4.

The normalised radiance is proportional to the ratio of the Earth's reflected radiance to the solar irradiance perpendicular to the solar beam. To this end, the smallest of either the AATSR pixel or the third-party ground pixel is averaged over the entire larger pixel. The normalised radiances over each pixel is then convoluted with the instrument response functions of AATSR. For the comparison, a partly cloudy scene over the ocean will be preferred, such that a large dynamic range is covered. The inhomogeneity of the scene also allows confirmation of the positioning and geolocation of the instruments.

6.3 Visible and near infrared reflectance validation against Arctic Stratus and Tropical CumuloNimbus clouds

Caroline Poulsen of RAL will provide calibration of the reflectance channels of the AATSR and MERIS instruments using cloud targets. Two methods and corresponding cloud types are utilised in conjunction with a multiple scattering plane parallel cloud model and NWP data to aid definition of atmospheric conditions. This work is funded by ESA as an activity for MERIS, and hence calibration of the MERIS instrument is the main priority. Calibration of AATSR reflectance channels will also take place however. The work is described in AD8 (the MERIS Cal/Val implementation plan).

Two methods of calibrating AATSR data are used. In the first method, Arctic stratus clouds are used to absolutely calibrate 0.55, 0.67 and 0.87 AATSR channels, using a comparison of nadir and along track reflectances and knowledge of the bi-directional reflectance distribution function. In the second method, deep convection clouds in the tropical regions are used to intercalibrate the 0.55, 0.67, and 0.87 μm channels by comparison of nadir view data and correction for residual above-cloud atmospheric effect. The target reflectance is more or less insensitive to the underlying surface or overlying atmosphere when a very deep cloud over ocean is observed. Radiative transfer models provide an estimate of the ratio between expected reflectances at non-absorbing wavelengths.

6.3.1 Progress to date

Further details of analysis are given in [RD3 and RD4]. In summary, Caroline Poulsen from RAL has tested the absolute calibration of AATSR using Arctic stratus clouds and also an intercomparison of AATSR (and MERIS) spectral channels against tropical convective clouds. The conclusions are that:

1) For absolute
   a) There is a slight positive bias of ~ 2-3% across the AATSR reflectance channels.
   b) No significant sensitivity to ozone or aerosols
   c) Calibration is sensitive to molecular scattering (0.55 and 0.67) channels.
   d) Results are sensitive to cloud top height
2) Inter channel calibration
   a) MERIS and AATSR well spectrally inter-calibrated with observed differences of 2-5%, similar to the results presented by Dave Smith

6.3.2 Activities for ongoing analysis

The current results from the validation using cloud targets are very promising. They show similar conclusions to the validation against desert sites in that AATSR and MERIS show good agreement to each other. The work is done on a best efforts basis and it is expected that ongoing activities in this area will follow the same work plan as before.

7 ONGOING VALIDATION OF OTHER AATSR PRODUCTS

7.1 Land Surface Products

As land constitutes only about one-fifth of the global surface and the heat capacity of land masses is significantly lower than that of the oceans, the properties of the land surfaces have, understandably, tended to receive lower priorities when investigating global climatic processes. However, the large inhomogeneity of land surfaces, notably their albedos, temperatures and transpiration properties means that, as climate models become more and more precise, there will be a great need for better information about the radiative properties of land surfaces. The AATSR can provide high quality data on Land Surface Temperature (LST) and on the reflective visible and emitted infrared properties of the land surface, which can produce a state-of-the-art vegetation index product that will provide information on vegetation dynamics.

7.1.1 Land Surface Temperature

The AATSR LST product has recently been installed into the operational Level 2 processor. Initially, the product was only produced using an add-on to the prototype processor (by Andrew Birks at RAL) in order for a through product evaluation phase to be carried out. Currently, there are three variants of the LST algorithm being validated. These are:

1. LST products produced using the prototype processor at RAL
2. LST products produced using a processor at CSIRO (Fred Prata)
3. LST products produced using a processor at NASA-JPL (Simon Hook)

The work done so far has involved comparisons against ground based *in situ* data across several sites in Europe, the USA and Australia. Validation at these sites has shown that the regression algorithm used in the LST processor is working well and comparisons with data from the National Center for Environmental Prediction (NCEP) network suggest that the global coefficients employed in the algorithm are delivering surface temperatures within ±2 K over a range of 240 – 300 K. Some individual *in situ* comparisons show differences greater than ±2 K and are attributed to unoptimised coefficients for particular surface environments. Some intercomparisons with MODIS data have been performed and show a lower bias for AATSR but similar standard deviations. The analysis carried out so far has shown several anomalous features including 1) differences between the CSIRO and RAL retrievals 2) certain land sites being classified as ocean and 3) problems with the cloud flagging over land. Further details of the analyses are given in RD3 and RD4.

One unusual instance of the LST retrieval is a lake surface temperature retrieval. Although the lake surface is obviosuly water, the standard SST retrieval scheme cannot be applied owing to topographical effects. One of the main validations sites of the LST algorithm has bene Lake Tahoe, which crosses the California/Nevada border in the western USA. Simon Hook from NASA-JPL has validated over one year of AATSR LST values, prodcued using his own processor. Over this time he observed a bias of 0.05 K between the AATSR data and the *in situ* data, whereas similar analysis for MODIS data showed a higher bias of 0.19 K.

The ongoing activites in this area will be to continue the fine work that has been started by all the LST valdiation team. The team currently consists of:

- Fred Prata (CSIRO)
- Simon Hook (NASA-JPL)

- Jose Sobrino (University of Valencia)
- Cesar Coll (University of Valencia)
- Julienne Stroeve (Colorado State University)

Specific taks to be investigated will include:

- Differences between the implementations
- Cloud flagging over land
- Covering all possible land surface types (10 out of 14 have been validated to date)
- More comparisons with MODIS and other sensors

7.2 Clouds and aerosols

Clouds and aerosols are an important consideration in AATSR retrievals of SST with requirements for cloud masking and for the correction of aerosol and thin cloud contributions to the observed brightness temperatures. Understanding of these effects is therefore an important consideration for SST retrieval.

The climatic importance of clouds and aerosols in moderating or amplifying radiative forcing is generally accepted. It is also generally accepted that our knowledge of cloud dynamic and radiative properties falls well short of that required by modern climate analyses and prediction schemes. Moreover, both clouds and aerosols feature strongly in AATSR data. Once the practical priority of identifying the presence of clouds in order to retrieve surface temperature has been satisfied there is much scope for using AATSR's multi-angle multi-wavelength viewing geometry to characterise and investigate the properties of clouds.

The sources of aerosols are diverse, ranging from large-scale natural events such as volcanic eruptions to desert storms, biomass burning and anthropogenic sources associated with industrial pollution and agriculture. The AATSR, on account of its unique dual angle viewing geometry, is especially sensitive to atmospheric aerosol and there is great potential for using AATSR data, generally in combination with data from other sources, to examine and quantify the radiative properties of atmospheric aerosols.

There are currently no plans to develop cloud or aerosol products.

8 REFERENCES

8.1 Applicable documents

AD1	PO-PL-GAD-AT-005 (1)	AATSR Validation Principles and Definitions (VIP Part 1)
AD2	PO-PL-GAD-AT-005 (2)	AATSR Validation Measurement Protocol (VIP Part 2)
AD3	PO-PL-GAD-AT-005 (3)	AATSR Validation Implementation Plan (Part 3 Versions 1 to 3)
AD4	PO-PL-GAD-AT-005 (3)	AATSR Validation Implementation Plan (Version 4)
AD5	PO-RS-GAD-AT-0001	AATSR Scientific Requirements
AD6	UL-SEP-P01	AATSR Science Exploitation Plan
AD7	PO-PL-RAL-AT-0501	AATSR Commissioning Plan

Table 8-1: List of Applicable Documents

8.2 Reference documents

RD1	M.R. Allen, C.T. Mutlow, G.M.C. Blumberg, J.R. Christy, R.T. McNider and D.T. Llewellyn-Jones, “Global change detection,” *Nature*, **370**, pp. 24-25, 1994
RD2	D. Llewellyn-Jones, M.C. Edwards, C.T. Mutlow, A.R. Birks, I.J. Barton and H.Tait, “AATSR: Global-Change and surface-Temperature Measurements from Envisat,” *ESA Bulletin*, 105, pp. 10-21, 2001.
RD3	Proceedings of the Envisat Validation Workshop, 9-13 December 2002, ESA-Esrin, Frascati, Italy, http://www.envisat.esa.int/pub/ESA_DOC/envisat_val_1202/proceedings/
RD4	Proceedings of the MAVT Workshop, 20-24 October 2003, ESA-Esrin, Frascati, Italy, to be published

Table 8-2: List of Reference Documents

9 ACRONYMS

AATSR	Advanced Along Track Scanning Radiometer
ARIES	Airborne Research Interferometer Evaluation System
ATSR-2	Along Track Scanning Radiometer 2
AVHRR	Advanced Very High Resolution Radiometer
BT	Brightness Temperature
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEFRA	Department for the Environment, Food and Rural Affairs
ESA	European Space Agency
FOS	Flight Operations Support
GHRSST-PP	GODAE High Resolution SST – Pilot Project
GODAE	Global Ocean Data Assimilation Experiment
ISAR	Infrared Sea surface skin temperature Autonomous Radiometer
LST	Land Surface Temperature
M-AERI	Marine Atmosphere Emitted radiance Interferometer
MAVT	MERIS and AATSR Validation Team
MODIS	Moderate Resolution Imaging Spectroradiometer
NCEP	National Centre for Environmental Prediction
NDVI	Normalised Difference Vegetation Index
NERC	Natural Environment Research Council
NOCS	National Oceanography Centre Southampton
NWP	National Weather Prediction
OP	Operational Processor
PI	Principal Investigator
RAL	Rutherford Appleton Laboratory
SAG	Science Advisory Group
SISTeR	Scanning Infrared Sea Surface Temperature Radiometer
SST	Sea Surface Temperature
TOA	Top Of Atmosphere
VIP	Validation Implementation Plan
VS	Validation Scientist