(A)ATSR Exploitation Plan
Volume 1

(A)ATSR Project Overview

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1 INTRODUCTION

1.1 Overview

The ATSR instrument series started with ATSR-1, funded by what was then the UK Science and Engineering Research Council (SERC) and launched on ERS-1 in 1991. This was followed by ATSR-2, funded by the UK Natural Environment Research Council (NERC), which inherited responsibility for the UK's scientific Earth Observation programme from SERC. ATSR-2 was launched on ERS-2 in 1995. The third in the series is AATSR, funded by the UK Department of the Environment (now Department of Energy and Climate Change, DECC) and launched on Envisat in 2002. All three (A)ATSR instruments were also part-funded by the Australian government. The fourth instrument in the series will be the Sea and Land Surface Temperature Radiometer (SLSTR), funded by the European Space Agency (ESA) as part of the Global Monitoring of the Environment and Security (GMES) programme. The series of ATSR instruments provide a very important long-term record of environmental variables, which support research studies and near-real-time/operational applications and products.

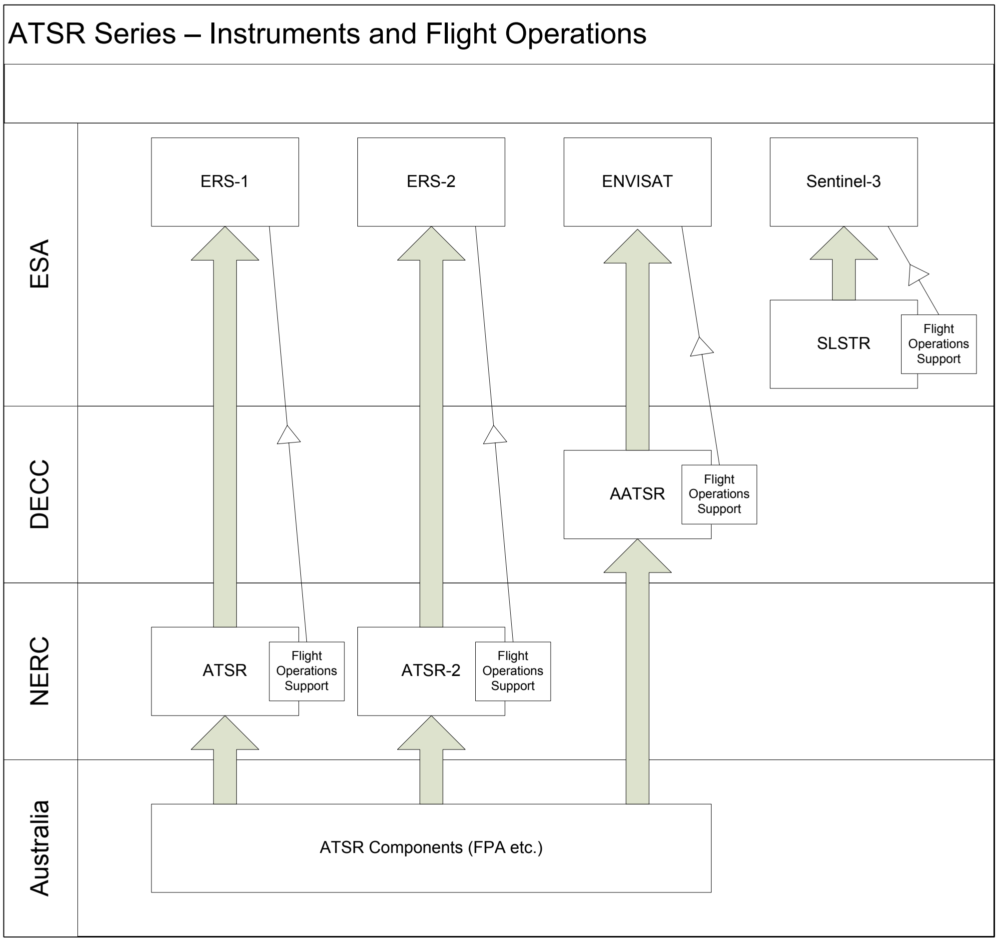

Figure 1-1: ATSR Series - Instrument Providers

The primary role of the ATSR series has been to make very accurate measurements of sea surface temperature (SST). For the first two instruments, this was done as a scientific development programme to verify the levels of accuracy required for climate research that were theoretically achievable from space using sound calibration principles together with a 2-angle (dual) view of the Earth's surface. The third instrument, AATSR, opened the possibility of extending the ATSR dataset to climatically interesting lengths in excess of 15 years. For this reason, AATSR was nationally funded by DECC because it was realised that AATSR has the potential to assist agencies, such as the Met Office Hadley Centre in the UK, to monitor climate change more accurately and to assist government bodies to develop national and international policies concerning the environment. The provision of input to the policy-making process involves monitoring, analysing and ultimately predicting manifestations of global climate change, a process for which AATSR provides key information of the highest quality.

In recent years, there has been a particularly important development in the provision of SST data from AATSR to operational users. This is an achievement of the Global Ocean Data Assimilation Experiment (GODAE) High Resolution SST Pilot Project (GHRSST-PP), which has opened the AATSR dataset to more users by providing the AATSR SST data in the international standard L2P format. Thanks largely to ESA's Medspiration project, which was the European contribution to GHRSST-PP, near real-time (NRT) AATSR data in L2P format are now being used in operational services. Since the end of 2008, the L2P product has been incorporated into ESA's operational system, thereby guaranteeing the ongoing availability of the service started by the successful Medspiration project. In addition, ESA is continuing to fund the GHRSST project office (GHRSST is now named the Group for High Resolution SST).

Thanks also to the success of the GHRSST project, AATSR data are now widely used to calibrate SST data from other satellite instruments that do not have the benefits of AATSR's dual view and on-board calibration. This has been a major breakthrough on the acceptance and use of (A)ATSR SST data worldwide and underlies the importance of engaging with the user community to develop common formats for important environmental variables derived from different instruments.

In addition to the primary SST product, ESA has developed a fire atlas product and a Land Surface Temperature (LST) product, which has been added to the suite of ESA products, and prototype cloud/aerosol products are in development. Further products, including a lake temperature product are on the horizon. These developments have been greatly assisted by the provision of a consistently-formatted set of ATSR-1, ATSR-2 and AATSR data in both Envisat and L2P format, produced by ESA, DECC and NERC under the direction of the (A)ATSR Quality Working Group (QWG).

With the expansion of the product suite and the availability of a consistently-formatted (A)ATSR archive, it is timely to consider the further exploitation of (A)ATSR data by the wider community. The purpose of this (A)ATSR Exploitation Plan (AEP) is to provide a framework for the information and guidance of funding agencies. This will also assist the data-providers to develop efficient strategies for the expansion of the (A)ATSR product suite and user base, including the development of joint products with other instruments on Envisat and other satellites. These developments are intended to support, in particular, the production of Essential Climate Variables (ECVs) to support ESA's climate change initiative and similar initiatives of the other funding agencies.

1.2 Heritage of the AEP

The AEP is based on an earlier document, the (A)ATSR Science Exploitation Plan (SEP). The (A)ATSR Principal Investigator (PI) and his team, together with the (A)ATSR Science Advisory Group (SAG), were tasked by DECC (or more accurately the Global Atmosphere Division within the Department for Environment, Food and Rural Affairs, Defra) to ensure that certain key scientific questions for which the use of AATSR data could help and strengthen investigations, were identified and addressed within Defra's data exploitation programme. The result was the SEP, which addressed scientific issues of particular relevance to Defra's policy objectives. In addition, the SEP contained material that was relevant to the science and application interests of other funding partners. The SEP, therefore, provides an excellent basis for the production of a generalised AEP that encompasses the requirements of all the funding partners, as well as other existing and potential stakeholders in the (A)ATSR Programme.

1.3 Aims of the AEP

The main aims of the AEP are to:

1. Identify key scientific questions which are most relevant to Europe's long and short-term policy objectives, as well as wider scientific and operational issues which may be addressed productively through the use of (A)ATSR data.

2. Show how the (A)ATSR programme can provide important data to address these questions.

3. Record the main recent, current and planned activities that constitute the implementation of this plan.

4. Suggest priorities for the future (A)ATSR exploitation programme, including the evolution of existing products and the development of new products.

The AEP is intended to act as a ‘shopping list’ addressing the needs of all the users of (A)ATSR data, including:

- Policy makers e.g. DECC, Defra, EU
- Product providers e.g. ESA, NEODC
- Scientific research e.g. NERC, Met Office Hadley Centre
- Operational users e.g. DUE, SST-TAC, Met Services

The AEP enables all these users to have a global picture of (A)ATSR exploitation, showing how the activities undertaken by all the funding partners fit in with their own needs. This then promotes further synergy and collaboration amongst the partners, enabling each partner to benefit from the investments made by the other partners. In particular:

- Funding Bodies can easily identify which investments meet their needs
- Scientists get easier funding for their research activities if they are listed in the AEP
- The (A)ATSR activities are all seen in an overall context and synergy can easily be exploited (fast progress in the life cycle from science, applications, operational use)

One use of the AEP will be to address how (A)ATSR can be used to provide data relating to the ECVs defined by the Global Climate Observing System (GCOS), and similar variables that may be defined by other international groups from time to time. This will require particular care as (A)ATSR and other EO datasets become integral to ECV development. The (A)ATSR programme will need to adopt a formal position on datasets for climate, with a clear verification and recognition process for official adoption of products (see also section 1.6). Clarity on the official recognition of products will enable a more effective exploitation of (A)ATSR data by users.

The AEP also describes specific programmes of scientific research and operational applications, including the responses to the Envisat Science Announcement of Opportunity (AO) and the GMES programmes, and their relationship to the scientific questions detailed in the body of the document.

This document cannot be exhaustive and the non-inclusion of a particular area does not necessarily imply that the area has low scientific or operational importance. As the exploitation of (A)ATSR data continues to expand and the user requirements develop, additional areas may be added to the plan. Hence, the AEP will be an evolving document through the lifetime of the AATSR programme. Responsibility for maintaining the AEP will rest with an (A)ATSR Exploitation Board (AEB), as described in section 1.6.

In summary, it is a major aim of the AEP to stimulate the gradual improvement of the accuracy and scope of the products that include (A)ATSR data, by outlining the scientific research and operational activities that would need to be funded by one or more of the existing or potential funding agencies to achieve the intended improvement.

1.4 Format of the AEP

This document is Volume 1 of the AEP. The document currently has five further volumes:

Volume 2 Projects that have requested (A)ATSR data

This volume lists all known projects that have requested (A)ATSR data

Volume 3 Peer reviewed literature citing (A)ATSR

This volume lists peer reviewed scientific literature that have used (A)ATSR data.

Volume 4 SST

This volume summarises applications of remotely sensed SST

Volume 5 LST

This volume summarises applications of remotely sensed LST

Volume 6 Aerosols and Clouds

This volume summarises applications of remotely sensed clouds and aerosols

Further volumes will be added as additional applications mature.

The volumes are also intended to complement the material in the (A)ATSR Validation Implementation Plan (VIP), which explains how the products outlined in the AEP are validated by *in situ* measurements. The VIP is maintained by the (A)ATSR Validation Scientist (PI) and is available at http://www.leos.le.ac.uk/aatsr/howgood/validation/documentation.html .

1.5 Format of this volume

This volume is split into five sections:

1. Introduction

This section provides an overview of the AEP, its aims, heritage and structure.

2. Policy areas

   This section describes policy issues, particularly in the funding partners' areas of responsibility, to which (A)ATSR data might make a contribution. The section describes the high level requirement for the application, the scientific developments needed to support the application, the maturity of existing products that could support the application and a development route for new products that may be needed.

3. Related Scientific Research

   This section describes scientific research which is necessary to provide a sound basis for the development of the (A)ATSR applications as well as the products that are needed in each application area. This is the type of activity traditionally coordinated by the (A)ATSR Science Advisory Group (SAG) and which could be co-ordinated by a new, more international scientific body in the future.

4. Operational Applications

   This section describes the pre-operational and operational applications which might address the requirements of operational users, including potentially useful operational services that may not yet be in use.

5. Underpinning Activities

   This section describes supporting activities such as calibration, validation, algorithm development and data delivery, which are essential if the activities of the previous three sections are to be carried out effectively and credibly.

1.6 Strategy for updating the AEP

The AEP is intended to set a framework for the development of (A)ATSR products through a combination of research-orientated and operational activities. These will depend on *ad hoc* funding opportunities, successful proposals, personnel issues and other unpredictable factors. Therefore, it is important to elaborate the funding partners' priorities in the context of AATSR's excellent performance and the seventeen year archive of (A)ATSR data.

The AEP will be developed in response to the requirements of the (A)ATSR Exploitation Board (AEB), which will have overall responsibility for the development and maintenance of the plan. It is anticipated that the plan will be updated on an annual basis and will be freely available on a new website dedicated to (A)ATSR.

The AEP complements other documents and web based material that describe the ATSR-1, ATSR-2 and AATSR projects in detail. These are currently accessible through searches on the web but it is intended to include links to these resources via the proposed new website. Appendix B lists the current set of (A)ATSR products, for ease of reference.

1.7 The (A)ATSR Exploitation Board (AEB)

As stated above, the AEB will have overall responsibility for maintaining and developing the AEP, and its member agencies will be expected to provide funding for future projects that are of particular interest and relevance to them, based on the information and suggestions contained in the AEP. In this way, a co-ordinated exploitation of (A)ATSR data can be achieved, to the mutual benefit of all parties.

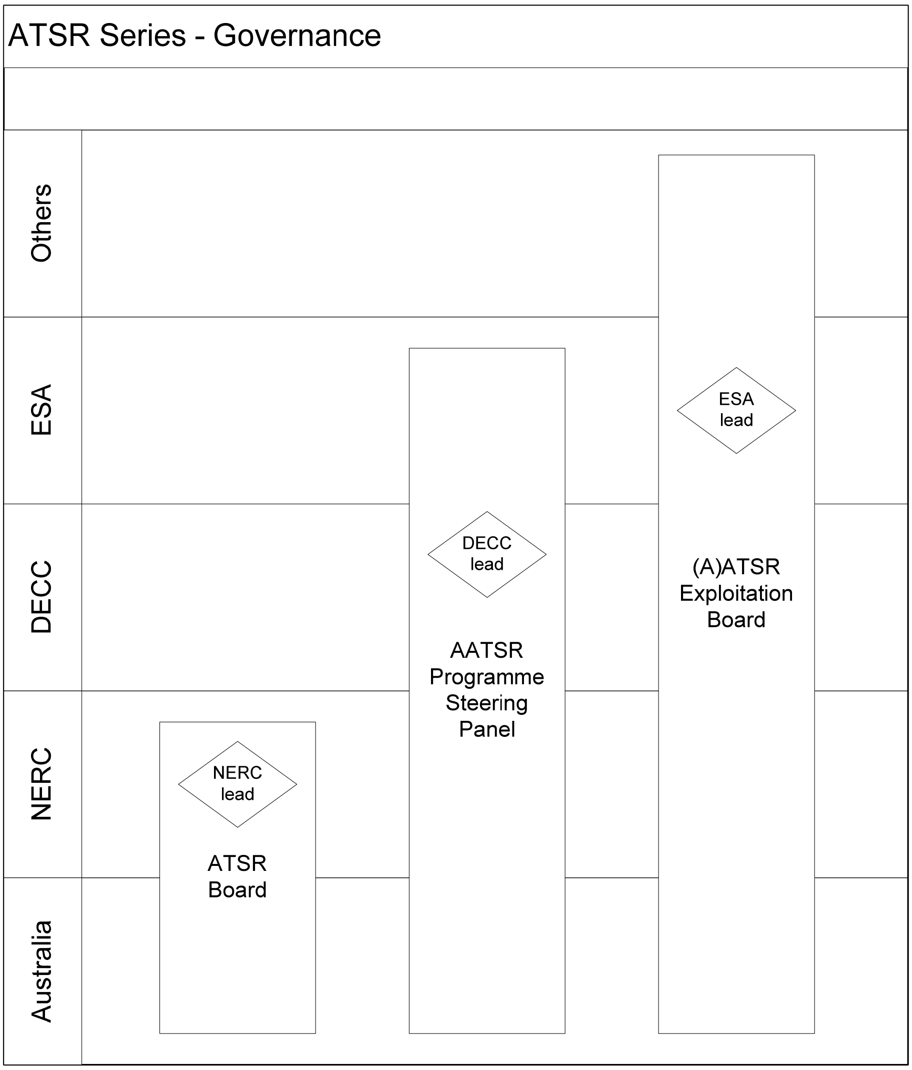

Figure 1-2: (A)ATSR governance

The AEB will be supported in its task by various bodies:

1. The (A)ATSR Principal Investigator Team
2. The (A)ATSR Science Team
3. The (A)ATSR Quality Working Group
4. (A)ATSR Users

The role of each of these bodies is described in the following sections.

1.7.1 The (A)ATSR Principal Investigator Team

The (A)ATSR Principal Investigator Team provides leadership to the (A)ATSR programme on behalf of DECC and in association with ESA. The team consists of a Principal Investigator and Scientific Manager, with supporting personnel, and works closely with the (A)ATSR Validation Scientist. The PI team provides an integrating function for the programme; monitoring instrument operations and operational processing, liaising between the partner agencies supporting the (A)ATSR programme, co-ordinating scientific inputs from the (A)ATSR community, and promoting exploitation of the data.

1.7.2 The (A)ATSR Science Team

It is important to take full advantage of the scientific experience and perspectives held by expert scientists. Up to now, the main scientific inputs to the (A)ATSR programme have been provided by the (A)ATSR SAG, which is sponsored by DECC and supported by all the other funding agencies.

At its 19th meeting held on 3rd March 2004, the SAG agreed to form topic teams to support the development of the AATSR Science Exploitation Plan according to the following topics:

1. Climate research and prediction
2. Ocean processes
3. Land surface processes
4. The atmosphere, including clouds and aerosols
5. The cryosphere
6. Operational applications, including meteorology

The AEP continues to address these scientific topics according to this breakdown, and SAG members have contributed to the document, according to their interests and expertise.

As the Envisat era evolves into the Sentinel-3 era, it is expected that the SAG will be replaced by a new scientific body that will include a wider range of international experts and that will be linked to the AEB. The exact mechanism for this to happen is to be formulated by the AEB and the (A)ATSR science team.

1.7.3 The (A)ATSR Quality Working Group (QWG)

The (A)ATSR QWG is charged with improving the quality of the (A)ATSR data products and for approving the production of new products, in response to AATSR validation results, processing improvements and algorithm improvements resulting from scientific research. It is the forum in which ESA and DECC co-ordinate the development of the mirror archives that contain the official products approved by the QWG.

The QWG is sponsored by DECC and ESA, who share the responsibilities for leading the quality effort. DECC fund the (A)ATSR Validation Scientist, who co-ordinates the *in situ* measurements that validate the quality of the AATSR data, whist ESA provides the QWG secretariat and the team who verify the format and integrity of new or modified products that are destined for the mirror archives.

ESA plan to maintain the QWG into the Sentinel-3 era. As with the Science Team, a formal link to the AEB has yet to be formulated.

1.7.4 (A)ATSR Users

The wider user community will be encouraged to use (A)ATSR data and feed back their comments and recommendations to the Science Team, QWG and AEB, as appropriate. Operational users will be represented directly at the AEB by the GMES SST Thematic Assembly Centre (SST-TAC). Currently users meet at the bi-annual MERIS-(A)ATSR and Envisat workshops. The AEB may consider whether a more dedicated (A)ATSR Users Forum would be beneficial.

2 POLICY AREAS

2.1 Policy requirements

Several European governmental bodies, including Defra and DECC in the UK, are required to devise and deliver policies to meet national and regional government priorities. For example, Defra and DECC use an evidence-based policy model to formulate policy goals and targets, for which practical solutions (including innovative approaches when needed) are required.

The policy goals and targets require the gathering and analysis of long-term, consistently formatted, well calibrated and validated environmental and socio-economic datasets. These datasets provide the evidence for the policy decisions needed to mitigate and adapt to adverse environmental changes, including climate change. The datasets also deliver a monitoring function which allows extreme environmental events to be identified and characterised close to the time of occurrence.

This section describes some policy-driven issues to which (A)ATSR data can make a significant scientific contribution.

2.2 Climate change

2.2.1 The climate change issue

There is increasing scientific evidence that human activity is changing the global climate through the emission of greenhouse gases, principally from the burning of fossil fuels and deforestation. The Intergovernmental Panel on Climate Change (IPCC) projects that temperatures are highly likely to continue to increase, with the likely range of increase being 1.1°C to 2.9°C or 2.4°C to 6.4°C over the next 100 years depending on the scenario for greenhouse gas emissions. Arctic sea ice is expected to decrease strongly and sea level to continue to rise. The intensity of tropical storms is expected to increase, based on model predictions, and it is possible that the frequency of extreme weather events might grow. The detrimental impacts of climate change on the natural world and human society are likely to become increasingly severe. There is a clear need for improved diagnostics of the spatial and temporal patterns of global and regional temperatures. The policy concerns include:

1. By how much are the global temperatures increasing?
2. How do these changes vary with geographic location?
3. What is the anthropogenic component and what are the climatically important natural variations?

4. What type of political action might help to mitigate these changes?

5. What political actions are required to adapt to climate change?

Clearly, (A)ATSR data can provide a significant input to address the first of these and will contribute to answering the second and third questions because specific causes will lead to specific patterns and rates of change that can be quantified in (A)ATSR data. Obviously governments will not be in a good position to carry out the last two activities if the first three are not addressed in a timely and precise manner.

Of the ECVs that have been defined by GCOS, those to which (A)ATSR measurements can make a contribution are listed in Appendix A. An effective strategy for the (A)ATSR programme to follow would be to concentrate efforts on developing and refining the (A)ATSR data products which are relevant to that list.

2.2.2 Science requirements for (A)ATSR to support climate change policy

One important indicator of climate change is global SST and (A)ATSR's prime objective is to generate precise measurements of this ECV. Past analyses of global SST are based on ship and buoy measurements or use blended satellite SSTs that are in turn empirically tied to subsets of the same *in situ* measurements. Each data source may be characterized by different random and systematic errors which change in time, and the balance of data sources in the observing network also evolves, potentially introducing artefacts into the present SST record. In addition, SST analyses have larger errors over the extensive regions of the ocean that have been sparsely sampled, e.g. the seas south of 20ºS and the south-eastern Pacific Ocean. It is important to both science and society that changes in global surface temperature over recent decades are robustly quantified, at global and regional scales and so the errors involved in the climate record need to be understood and quantified as accurately as possible.

While painstaking research has been pursued to characterize and minimize artefacts in existing SST analyses, the temperature changes apparent in existing analyses will be more certain if tested against a record that is sufficiently independent. To be suitable, the new SST record needs to:

- Contain at least 15 years of continuous data
- Be independent from *in situ* records
- Have a stability of 0.05 K per decade
- Have biases less than 0.1 K

- Have estimates of both bulk and skin SST
- Have a comprehensive error characterisation

(A)ATSR can meet these criteria and help to achieve the goal, at least since the era of satellite SST measurements began, of a more accurate climate SST ECV record that also draws on the higher temporal coverage provided by other satellite measurements and *in situ* data from buoys and ships.

SST is the most important and highest priority data-product from (A)ATSR. However, other geophysical parameters measurable by the (A)ATSR instruments over land and the atmosphere are either ECVs or climatically important. These include, for example, land/lake surface temperature, aerosols/clouds, fires and land cover parameters. In addition, the (A)ATSR calibrated radiance data themselves contain information on changing radiation values. All these (A)ATSR products need to be developed and combined with other suitable sources of data to produce robust ECV climate records as summarised in Appendix B.

2.3 Environment and climate

The needs of policy makers in the areas of environment and climate include the following:

1. Information concerning past and present geophysical behaviour (i.e. observations)
2. Predictions of future geophysical behaviour
3. Analyses of the relationships between anthropogenic activities and the observed geophysical behaviour
4. Prompt information on unexpected or unusual environmental events.

Of these, 1 and 4 are the aspects that space observations contribute to directly. However, space observations are also inextricably linked to items 2 and 3, which are in the realms of scientists who investigate and seek to understand geophysical processes either directly using data or using models. Space datasets are used to initialise the models, test their closeness to current geophysical behaviour, and provide realistic forcing terms for model simulations. The AEP seeks to identify these links, to ensure that the (A)ATSR system meets the needs and objectives of policy-makers.

2.4 Other policy areas

National energy policies are inextricably linked to climate change issues and again, policy-makers need to be able to relate, quantitatively, carbon emission rates to climatic behaviour.

- Other policy areas which may be assisted by the use of (A)ATSR data might include:
- urban planning (land surface temperature observations of ‘urban heat islands’)
- air quality (aerosols, land surface temperature)
- land use management, in agriculture, forestry and change-of-use issues (land cover monitoring using AATSR reflectance channels)
- fisheries management (SST and ocean colour observations, especially of fronts and mixing processes which facilitate the identification of, for example, feeding areas, possible migration routes etc.)

Further policy areas may emerge as AATSR data exploitation programmes develop.

3 SCIENTIFIC RESEARCH

3.1 The scientific priorities

The information from (A)ATSR is generated at several levels, ranging from counts of brightness temperature at the top of the atmosphere to global scale monthly averages of surface parameters, notably surface temperature, measured at thermal infrared wavelengths and surface reflectance, measured at selected visible and near infrared wavelengths. There is also a great deal of information about clouds, particularly their temperature and some of their optical characteristics. The main qualities of (A)ATSR data which underpin its scientific importance are its excellent calibration, its dual view of the Earth's surface that can provide additional information about the atmosphere, its stability and its exceptionally precise image quality.

(A)ATSR's capabilities to achieve great accuracy and stability mean that it has clear science drivers in several areas, primarily relating to the detection of climate change. The main scientific priorities to be addressed by AATSR can be grouped into five categories:

1. Climate research and prediction
2. Ocean processes
3. Land surface processes
4. The atmosphere, including clouds and aerosols
5. The cryosphere

It will be seen from this document that climate change research inevitably overlaps substantially with the other categories. Also, of these five categories, investigation of the atmosphere with (A)ATSR observations is perhaps the new science area that is developing most rapidly at present and the cryosphere is the least exploited area in the current (A)ATSR exploitation programme.

The next sections elaborate these scientific priorities and describe some of the most important examples. In addition, system performance – the need to achieve and demonstrate the highest possible accuracy and stability – is an important issue which provides the technological underpinning of the data. It is inseparable from climate-related observations, where changes must be accurately measured over long time-periods. This is further discussed and explained in the following section.

3.2 Climate change research

3.2.1 What are the strategic scientific issues?

The strategic scientific issues follow from the question:

"To what extent are the observed changes due to anthropogenic causes?"

There are consequential questions concerning impacts. However, for the AEP, it is desirable to confine discussion to those issues which will be directly served by the analysis of observations. In this case the high-level questions are:

- To what extent are the ECVs served by (A)ATSR observations?
- Does AATSR achieve the appropriate accuracy to observe the climate-related changes expected in each ECV?
- What is the geographic distribution of these changes?
- Are the patterns of change observed in the (A)ATSR record consistent with expectations of 'natural variability'?
- In what other ways can AATSR observations improve our knowledge of the climate system?

The (A)ATSR datasets, particularly SST but also other ECVs and climate variables, will allow for some critical tests of climate change and its fingerprints. These contributions will occur in a number of ways, as independent datasets, as reference standards, and as model-assimilated information.

3.2.2 How can (A)ATSR contribute?

Do (A)ATSR SST data provide evidence of climate change?

The compelling work that needs to be maintained at the forefront of the (A)ATSR programme is the rigorous diagnosis of the satellite SST data record. For example, is there evidence of a trend in global SST values and do the patterns of change shown by SST derived from (A)ATSR data relate well to predictions from climate prediction models? These comparisons can be related to those obtained using (other) IPCC datasets and consistent or improved records will provide increased confidence and lower uncertainties in observed temperature changes. This is critical if interpretation and attribution of observed temperature changes is to be deduced over short timescales.

Can the satellite measured ocean skin temperature be consistently related to bulk temperature and is it a valid indicator of climate change? If so, how is the (A)ATSR temperature record related to the long-term record of bulk temperature?

An intrinsically related question concerns the relationship between the skin temperature, which is measured by space-borne radiometers such as (A)ATSR, and the bulk temperature on which the long-term climate record is currently based. The relationship of the skin-bulk temperature is also closely related to heat-fluxes which are occurring at the boundary between the ocean and the atmosphere. This subject is of particular importance to climate change research because currently the Met Office Hadley Centre make estimates of skin-bulk temperature differences, based on a certain specific formulations. These estimates are used to modify the (A)ATSR SST measurements before submitting them for incorporation into the climate record. This means that the accuracy with which we can estimate skin-bulk temperature differences has a direct bearing on the climate record and clearly needs to be accurate, robust and generally accepted.

What other parameters measured by (A)ATSR are indicators of climate change?

The increasing long-term record of (A)ATSR data measured in a consistent manner enables other (A)ATSR parameters to be examined in the context of climate change. This applies to products already identified as ECVs. In each case, it is important to demonstrate that the changes measured are related to climate change and not just natural variability. Examples of parameters which are subject to great natural variability, but which may also show trends indicative of climate change include cloud cover, cloud type, land cover, global aerosol distributions, ice cover, fire disturbance and lake surface temperature. In close relation to land cover, land surface temperature has been identified as a key subsidiary variable in supporting the understanding of land surface ECVs. In addition, the radiances produced by (A)ATSR are themselves a long-term record of top-of-the-atmosphere (ToA) radiation and can be used to study climate change directly (see below).

How well can we characterise natural variability?

Examples of natural variability which must be distinguished from long-term change include the seasonal cycle, the El Niño/Southern Oscillation (ENSO) and the North-Atlantic Oscillation (NAO), together with correlated effects which can be observed in the atmosphere and in land properties. Such processes must be accurately characterised so that they can be identified within the climate record and also so that changes in the phenomena themselves e.g. in the frequency and intensity of ENSO events, can be quantified, as such changes can themselves be indicators of climate change. The (A)ATSR SST record, for example, provides well sampled seasonal and inter-annual averages of data which are very suitable for examining these effects. The fingerprints of change in (A)ATSR data can help to diagnose the contributions of these different effects to the overall global change.

Can fluxes of heat and moisture across the ocean-atmosphere interface be inferred from (A)ATSR data (and other data sources) with sufficient accuracy to improve the performance of climate prediction models?

Although SST is undoubtedly an indicator of climate change, a direct mechanism by which SST affects the climate is that of heat transfer across the ocean atmosphere boundary. In the tropics, this transfer rate depends strongly upon SST. It also depends on other parameters, notably wind stress and near-surface atmospheric temperature and humidity. In climate prediction and meteorological forecasting models all the parameters are represented and the physical relationship between them and the surface-atmosphere fluxes are embodied in the formulation of the model, often using empirical relationships or assumptions of simple linear behaviour, which are subsequently “tuned” to optimise the performance of the model. The physical model of the specific process is complex and hard to verify, and it is sometimes not possible to incorporate a complete physical representation of such processes in models; air-sea heat fluxes are likely to remain one of the challenges for scientists to compute over the next decade. However, within the constraints of this physical modelling, it may be possible to use (A)ATSR data, in conjunction with other datasets, to estimate better latent heat fluxes and their geographical variations.

Can (A)ATSR top-of-the-atmosphere observations be used in climate research?

Much use for (A)ATSR data will come from the level 2 products. However, complications do arise in deriving variables such as SST from the behaviour of the atmosphere close to the surface, the resultant skin effect and difficulties in retrieval. In principle, there are other approaches to testing climate models.

The first approach which can be pursued is to use directly the (A)ATSR top of atmosphere (ToA) measurements (level 1b products) to test the climate model. This requires incorporation of state-of-the-art radiation schemes as well as a proper treatment of clouds and aerosol. The method avoids assumptions about the state of the atmosphere and instead would test the consistency of the modelled outgoing thermal and shortwave radiation. These radiation components could then be used to assess aspects such as global dimming/brightening. Whilst this is challenging, the elements are available and the approach is worth pursuing. Such studies are being pursued, for example, to examine global dimming.

In principle, an alternative approach is suggested by the increasing use of long-term collations of NWP model analyses (or re-analyses) as climate model datasets in themselves. A testing, but possibly informative study would be to directly assimilate the radiances into an NWP scheme, in a manner similar to Optimal Estimation (OE) approaches. In principle this approach would be more logical, avoiding modifications to the data through constrained independent retrievals or post-hoc adjustments, which introduce further assumptions and inevitable inaccuracies. This is an ambitious target as such an assimilation model would need to incorporate appropriate radiative transfer schemes and would depend on the ability to fit to AATSR data as compared to other assimilated datasets. Again, the elements are in place and would be interesting to test, given the experience of met agencies in handling satellite datasets.

Can we further quantify the sensitivities to SST and LST of climatically important processes such as rainfall or deforestation etc.?

There is, for example, a well-documented relationship between the onset of the Indian Monsoon and SST on the Indian Ocean. Also, there is now an established but poorly understood relationship and/or correlation between the occurrence of El Niño phenomena and the behaviour of certain land-cover parameters, for example NDVI. There are other similar relationships which need to be understood and the importance of proper monitoring and prediction of these events is obvious owing to their devastating effects. By providing more accurate data for these variables, (A)ATSR may permit better quantification of these relationships.

Can (A)ATSR data be used to detect anthropogenic effects which are relevant to climate change?

Anthropogenic effects are highly likely to be contributing to climate change. The most obvious example of this is biomass burning, where the fires themselves, the resultant changes in surface properties (burned area), and the evolved aerosol can be observed. These factors, which can be directly measured by the (A)ATSR instruments, both contribute to climate change and are changed themselves by climate change (e.g. in geographical extent and in intensity). The (A)ATSR data products can be used very successfully to study these changes and their interactions with global and regional temperature changes. Whilst biomass burning is the most obvious example in this category, there are undoubtedly others, e.g. urban heat islands.

3.2.3 Further remarks concerning (A)ATSR and climate research

In this section, a number of remarks are made with respect to the priority target for (A)ATSR, which is the SST record. Many of these remarks might also apply to the other (A)ATSR products.

The (A)ATSR scientific requirements for SST were derived on the basis of the data needs of climate research, which lead to the requirement that (A)ATSR'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, for example, reasonably accurate tracking of major SST anomalies, such as El Niño, which are typically of 3 to 4 K in magnitude and would need to be tracked with an accuracy of at least one-tenth of the maximum signal.

However, for the accurate detection of global change in the SST fields, the requirements are more stringent [RD001] raising a number of questions concerning the accuracy and consistency of the data. In fact, the need to detect a change rate of 0.1 K per decade with an error of less than 10% leads to a stated need for system drift of less than 0.01 K per decade [RD001]. This raises some profound questions about the ultimate accuracy of the measurement process.

Once the necessary accuracy for the detection of global change from a long time-series of data has been established, 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 from (A)ATSR 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 and mask or distort observations of the actual warming trend. Overall, the scientific priority must be to generate and examine time-series of (A)ATSR data in order to quantify and to separate natural variability and trends in the (A)ATSR record of global SST.

The applicability of (A)ATSR SST to climate change is an extremely mature concept in terms of instrument design and calibration, although some small improvements in system performance are required. At the time of writing, the engineering design and performance of (A)ATSR are close to ideal and the main limitation to accuracy is the atmospheric correction. As such, there is a continued need to investigate the basic spectroscopic properties of the atmosphere at the (A)ATSR wavelengths and to generally improve the clear-air retrieval scheme. Some continuing attention will need to be paid to characterisation of instrument drifts, which are believed to be extremely small but nevertheless quantifiable.

At present the retrieval scheme for SST is mature and undoubtedly performs very well. However, some deficiencies are manifested in the observed latitude-dependence of the accuracy and in differences seen between 4-channel and 6-channel retrievals. It is clear that there are still some small effects within the atmospheric correction, either with the spectroscopic data used or the actual formulation of the retrieval algorithms, which are still being addressed.

Perhaps a more important scientific aspect of system performance is that of cloud detection when retrieving SST. The methods used by (A)ATSR are very well-developed and are mainly based on several threshold and spatial uniformity criteria. However, the cloud identification over sea is not perfect and also the problem of cloud-detection over land is still a serious one to which improved solutions would be desirable. Thus, work which seeks either to improve the existing cloud detection scheme or to explore new and different methods which have the potential for operational implementation need to be given high priority in the system performance area. It should be noted that the ability to detect clouds quantitatively is also a priority in a significant area of atmospheric and climate research, which further strengthens the case for promoting further work in this area of (A)ATSR system performance.

In addition to the requirement of meeting its specifications, (A)ATSR is measuring in a regime where improved accuracy will always provide improved scientific return. This is because the rate of ocean-atmosphere heat transfer is critically dependent on sea surface temperature (SST) and thus in the tropics, a change of SST of less than 0.1 K will give rise to significant changes in heat transfer. Therefore, any action to improve accuracy will be valuable to the scientific return of (A)ATSR.

What is the ultimate accuracy that can be achieved by (A)ATSR in the measurement of surface temperature?

Although (A)ATSR has specified accuracy requirements which it is designed to meet, there are strong scientific arguments for achieving the highest possible accuracy with the instrument. The question has two aspects. The first of these is a simple analysis of the measurement of the radiometric process (i.e. how well (A)ATSR measures top-of-atmosphere radiances) and the associated atmospheric corrections etc. The second aspect concerns the nature of the ultimate target – the sea surface. It is arguable that variations and in homogeneities in the sea surface itself, coupled with variations in atmospheric conditions, would impose an ultimate geophysical limit on the accuracy achievable by a near perfect radiometer such as (A)ATSR. This is an important question because if there is such as limit, it is necessary to concentrate much more strongly on the top-of-the-atmosphere brightness temperature measurements which are made directly by (A)ATSR with high levels of accuracy, and which arguably should be assimilated into models, as discussed in the previous section.

It is also the case that within the (A)ATSR period, there are periods where the data must be subjected to the most rigorous checks. The most obvious example is the period of the Mt Pinatubo eruption in the ATSR-1 record where the data could have different characteristics than the rest of the record for both instrument and atmosphere reasons. In instrument terms, there is enhanced noise due to pick-up from the coolers and also a drift in detector temperatures. In atmosphere terms, there is also a large injection of stratospheric aerosol which renders comparisons with other satellite datasets more difficult. Therefore, the ATSR-1 period of data is important but requires some careful re-visiting and further investigations.

3.2.4 Recommendations for future work

There are some important recommendations for future work:

1. IPCC datasets for surface temperature should be inter-compared to (A)ATSR data to reduce the errors associated with global temperature analyses.
2. The data quality and uncertainties of other (A)ATSR data products such as LST, lake temperature, aerosols and clouds should be subject to review and rigorous characterisation as appropriate and in a similar manner to SST.
3. Suitable (A)ATSR datasets should be examined for their long-term behaviour in conjunction with equivalent *in situ* data records.
4. Effort should be put into data product improvements to climate quality where required.
5. Climate models should be inter-compared to (A)ATSR datasets for the relevant time periods.
6. Direct radiance testing of climate models should be assessed.
7. The assimilation of (A)ATSR data into NWP models should be tested.
8. Some additional effort should be put into the understanding of instrument and atmosphere effects in the ATSR-1 period.

3.3 Ocean processes

3.3.1 What are the strategic scientific issues?

3.3.1.1 Overview

Most of the well-known dynamical ocean processes can be observed in (A)ATSR data, as SST is an excellent tracer for currents and other dynamic structures at the surface. The strategic question is probably: *"Can we detect departures from the normal regimes of natural variability in the behaviour of ocean processes?"*

For this, accurate quantitative data are required, but, for meso-scale or smaller processes, both the temporal and spatial coverage of a single sensor is probably inadequate and (A)ATSR data, with a particularly narrow swath width, are best used in conjunction with other sensors which give greater coverage. The methods by which such data are combined are referred to in section 4 (Operational Applications). Hence there are likely to be two routes for exploitation of (A)ATSR data, i.e. direct comparison with, or use of AATSR SST data and indirect (but important) exploitation of AATSR data via an operational analysis or model assimilation system.

Given the spatial and temporal coverage of (A)ATSR, many of the direct uses of (A)ATSR data will either be in the form of averaged datasets, e.g. weekly, seasonal, regional, global averages, or use of either single or a few images of ocean phenomena. This review concentrates more on the former application. Where higher spatial and temporal coverage is required, the OSTIA system, developed and operated by the UK Met Office and further described in section 4 of this volume, is a daily multi-satellite SST analysis, which gives the improved temporal and spatial coverage needed, combined with the high levels of accuracy provided by the AATSR data. The analysis field is very well suited to the investigations of meso-scale oceanic processes, which need good SST accuracy as well as good spatial and temporal coverage.

It should also be noted that the climate analysis of (A)ATSR data, reviewed in the previous section, will likely shed much light on ocean processes and so there is much synergy between the understanding of climate and the understanding of departures from the normal regimes.

The sea surface temperature is important in driving atmosphere processes so a potentially significant application of (A)ATSR data is to the study and characterisation of large-scale ocean-atmosphere coupling.

3.3.1.2 Sea Surface Temperature

If SST is to be used as a true indicator of climate change, it is important that 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, the Kuroshio Current and the Agulhas Current. Research into the behaviour of such phenomena, particularly with respect to quantifying their intensity and geographical extent, should receive high priority. A highly relevant scientific question concerns the relationship between global SST and the 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 should receive high priority.

See Volume 4 for more information on SST.

3.3.2 How can (A)ATSR contribute?

Can (A)ATSR data help identify the mechanisms that drive El Niño and help predict El Niño events?

The oceanic manifestation of an El Niño event begins with an increase in surface temperature, along with the generation of solitary waves along the equator. If the warming and associated waves can be identified in (A)ATSR data prior to El Niño taking place, predictability in models may be enhanced. At the same time, the driving mechanisms and response to those waves could be identified, so that the excitation mechanisms for El Niño, which may involve the atmosphere, could potentially be explored. Currently a number of theories still exist as to the mechanisms for triggering of an El Niño. In particular, recent research has shown that the understanding of warm water movements and sea level may have changing relationships to the observed SST anomaly fields. This requires further investigation.

Can (A)ATSR SST data be used systematically to identify Rossby waves?

Rossby waves form an important class of processes in the ocean, determining the response of the ocean to a wide range of forcing processes, including atmospheric forcing and internal ocean processes. Identifying Rossby waves is essential to testing model hypotheses. It has been shown that the rather small SST signatures of Rossby Waves can be identified from (A)ATSR under certain circumstances and such observations need to be made more systematically.

Can (A)ATSR SST data be used to identify and quantify the behaviour of eddies in the global oceans?

Several studies indicate that eddies in the oceans are an important process for driving heat vertically, or for providing nutrients through the associated upwelling and downwelling fields. Eddy-induced vertical mixing will also affect the relationship between SST and oceanic heat content, mentioned above. The (A)ATSR data can provide very high spatial resolution observations of eddies, albeit with some assessment of cloud clearing and dual-nadir alignment, and ocean models are now beginning to approach the required resolutions. Studies of the ability of (A)ATSR data to provide statistical information on the mean state and evolution of eddies would be timely.

Can (A)ATSR data help identify processes with the potential to change the major ocean current systems?

There is much interest, and concern, in potential changes of major current systems, such as the Gulf Stream, the Kuroshio current and coastal boundary currents. The most obvious of these is ice-melting in the North Atlantic which has the potential to 'nudge' the Gulf Stream away from Northern Europe. The (A)ATSR SST data can be used to study the consequences of these changes, which can include freshwater flows and atmospheric circulation. The changes in the Arctic region observed in recent years have been very striking and have raised these questions to a high scientific level.

Changes in other current systems have been less commented on using satellite data and further investigation of these (see Further Remarks below) may well yield some interesting developments.

Can (A)ATSR data provide an early indication of change in major cyclical events in the ocean that drive climatic phenomena?

This is a more general question which applies to many of the phenomena mentioned above. It is clear that "early indicators" are becoming of increasing importance, most fundamentally for climate change but also for improving seasonal to decadal prediction skills. For example, research has suggested that SST and salinity changes lead those in the Atlantic meridional overturning circulation by two years and potentially could be used as predictors. Some applications will work directly with the data, particularly those which can be addressed with some temporal and spatial averaging. Many other applications will derive full benefit from analysis systems (see Section 4) and assimilation systems which exploit (A)ATSR data.

Can (A)ATSR data be assimilated into oceanographic models?

A positive impact of (A)ATSR SST data has been achieved in operational meteorology, albeit not by assimilation. The same could potentially be achieved by good assimilation into oceanographic models which are developing in their ability to represent the sea state in an operational manner. Some increasing research is being carried out in this area but much further work is required, particularly to examine how SST adds to altimetry data in assimilation and what other datasets are required for the assimilation of SST. Idealised experiments might also look at the consequences of assimilating a smaller amount of highly accurate data versus larger amounts of less precise data.

3.3.3 Further remarks concerning (A)ATSR and ocean processes

Exploitation of (A)ATSR SST for global climate studies and for operational oceanographic analyses is a maturing subject. Further emphasis on two areas is likely to encourage exploitation:

1. The development of appropriate temporal and spatially gridded products to support oceanographic model comparisons

2. Easy access to both SST (and possibly brightness temperature) imagery from (A)ATSR.

For the first case, some interaction with modellers is required to define useful spatial and temporal scales, missing data gaps, and uncertainties. Some careful thought would have to be given to the appropriate averaging scales for (A)ATSR data. One useful product is likely to be production of SST climatologies e.g. annual, semi-decadal, which show the average global state as observed by (A)ATSR. Such climatological averages may give excellent indications of the evolution of the sea state. These may also find useful applications in ocean phenomena, such as ocean biology, which are sensitive to SST.

For the second case, the current data archives allow child product access to the archive. It may be useful and appropriate to either activate simple plotting tools for the archive data or to enable users to plot the data in any easy manner, for example using BEAM; a complication is that in regions of strong SST gradient, cloud screening may need to be corrected. Another possible way to encourage users might be to choose important oceanographic features and produce time-series of data for a number of cases (possibly as a result of user request). Finally, it is worth commenting that some increased exploitation might result from the provision of a sub-skin SST dataset. These would involve adjustments for skin effects, including diurnal warming, where possible.

3.3.4 Recommendations for future work

A number of recommendations for future work can be made:

1. The development of gridded SST data for (A)ATSR at temporal and spatial scales which are useful to ocean modellers.

2. The promotion of (A)ATSR SST plotting utilities and easy access imagery.

3. The promotion of increased interaction between the (A)ATSR SST community and the wider oceanographic community, particularly with respect to El Nino, North Atlantic and boundary current studies.

4. The support of studies into the assimilation of (A)ATSR SST data into ocean models.

5. Provision of an operational sub-skin SST product from (A)ATSR

3.4 Land surface processes

3.4.1 What are the strategic scientific issues?

3.4.1.1 Overview

(A)ATSR can provide high-quality data on Land Surface Temperature (LST) and on the reflective visible and emitted infrared properties of the land surface. It also produces a state-of-the-art vegetation index product which will provide information on vegetation dynamics. The following sections highlight specific land surface processes where exploitation of data from the (A)ATSR can make a significant contribution.

3.4.1.2 Land Surface Temperature

Land surface temperature is a highly significant quantity because it is a prime driver for terrestrial radiation, it is a controlling factor in surface energy (heat) and moisture fluxes from the land to the atmosphere, it is an indicator of climate change ranging from temperature trends to drought, and has a large influence on vegetation growth and global primary production; polar land surface temperatures are just one area of primary concern. LST is significantly coupled to the atmosphere so that in it is highly influential in convection in the atmosphere and it also is a strong influence on biogenic emissions of gases from the land to the atmosphere. Differing land surfaces produce very different LSTs and this has important consequences, e.g. for moisture and rainfall. There are also immediate consequences for public health, e.g. in urban heat islands. LST and air temperatures have been shown to be significant factors in disease vectors and their epidemiology.

For meteorological reasons, current monitoring stations on land measure near-surface air temperatures rather than land surface temperatures. Since satellites measure the latter, these data become immediately more exploitable if the two can be related as there are large gaps in the global coverage of the *in situ* datasets. Studies have shown that this is possible if account is taken of the vegetation state of the surface; presumably knowledge of wind will also lower the errors in inferring air temperatures from LST.

The strategic scientific questions include:

- *“Can we relate large-scale changes in land cover to changes in oceanic behaviour observed by (A)ATSR e.g. El Niño events and associated anomalies?”*
- *“Can we relate LST data to soil moisture, transpiration rates and/or general fertility of the soil?”*
- *“How does LST relate to meteorological predictions and to meteorological events?”*
- *“With what confidence can air surface temperature be computed from satellite LST?”*

In urban areas:

- *“Can LST data be related to public health issues, probably when combined with atmospheric data?”*
- *“Are there applications of LST data in environmental management?*

See Volume 5 for more information on LST.

3.4.1.3 Vegetation monitoring

Information on the reflective visible properties of the land surface is obtained from the three visible channels on ATSR-2 and AATSR, at 0.56 μm, 0.67 μm and 0.85 μm. In addition, a vegetation index product is produced from the ratio of the 0.67 μm and 0.85 μm reflectances. On account of the bandwidths chosen for (A)ATSR, the vegetation index should be similar to those derived from MODIS or the VEGETATION satellite. However, with its dual-view, there is the potential to derive an atmospheric optical depth (North et al) which can provide an atmospheric correction. This will yield a vegetation index (or related indices) of much higher quality than has been possible to date. This means that, in the future, the ATSR-2 and AATSR sensors have the potential to provide major improvements in our ability to provide good quantitative data on vegetation cover. Also, by utilising the higher spatial resolution of some other similar sensors, the atmospheric correction from AATSR could be applied to higher resolution data from other sensors in a synergistic way which will offer further benefits the fields of quantitative land-cover monitoring.

3.4.1.4 Deforestation

The Earth's forests play an important role in absorbing carbon dioxide from the planet's atmosphere, and their destruction will contribute to the Greenhouse Effect. On a local scale, deforestation has had dramatic effects on the climate with the combination of reduced rainfall and soil erosion compromising attempts at agricultural use of the cleared land. Clear evidence of the anthropogenic origin of this destruction is the regularity and linearity of the inroads that have been made into the forest. Many remarkably straight tracks are clearly seen in (A)ATSR images. These cleared areas show up brighter than the surrounding vegetation because they have different thermal properties and can be up to 4K warmer during the day. Ground-based estimates of the scale and rate of deforestation are notoriously inaccurate. However satellite images provide a reliable and convenient method for long-term global monitoring of this phenomenon and burned area is derived from SPOT data, for example. These methods are likely to be increasingly applied to (A)ATSR data as well.

3.4.1.5 Volcano monitoring

The 1980s was the worst decade for volcanic disasters in the twentieth century, with 24,000 to 28,000 fatalities associated with each of two particularly devastating eruptions, that of El Chichón (Mexico, 1982) and Nevado del Ruiz (Columbia, 1985). Such tragedies clearly show that active volcanoes continue to represent extreme hazards, despite advances in the technology available for ground-based monitoring of pre-eruptive volcanic phenomena. In addition, there is the problem of the sheer number of potentially active volcanoes whose monitoring needs to be addressed. The Catalogue of Active Volcanoes (CAVW, 1951-1975) documents over 500 volcanoes that have had recently dated eruptions and, on average, more than 50 eruptions occur annually. With such a huge number of potentially active volcanoes, traditional monitoring approaches such as seismic and microgravity techniques require assistance if all these targets are to be kept under surveillance.

The (A)ATSR series of instruments has been used for volcano monitoring since its channels are variously sensitive to a range of thermal signals. In particular, at night-time, the 3.7 µm and 1.6 µm channels both have sensitivity for very hot active sites in addition to the ability to sense lower contrast thermal signals with the conventional 11 and 12 µm channels; the ability to use the 1.6 mm channel at night represents a semi-unique capability. The (A)ATSR instruments, however, are not ideal for these measurements because of the low coverage (swath and clouds) and also because of non-ideal channels. Future instruments will improve on these capabilities with an extended swath, extended range for 3.7 µm and sub-pixel resolution to identify small areas of high thermal output. This will give the opportunity to extend the current (A)ATSR volcano monitoring service to one with more coverage of volcanoes and higher repeat times. It is worth noting, in addition, that aerosol products from (A)ATSR afford some additional opportunities by providing data on aerosol plumes.

3.4.1.6 Fires

The (A)ATSR data have been used extensively for indicating the location of fires in localised and continental-scale studies, for estimating gas emission fluxes to the atmosphere, and in understanding seasonal and interannual cycles in fire. Based on threshold tests in the 3.7 µm channel, the ESA ATSR World Fire Atlas is available on the web and has many hundreds of users. The timing of the (A)ATSR observations are not ideal for observing fires but the (A)ATSR channels provide a long-term record of fire over the globe, whilst optimisation of its channels in the future could improve its sensitivity to fire products. In addition, observations of visible surface reflectance also allow burned areas to be quantified from (A)ATSR data and this contributes a synergistic product which can be used in addition to the fire data.

3.4.2 How can (A)ATSR contribute?

As for SST, (A)ATSR LST data will contribute either directly or through integration with other systems. A particularly important step forward would be the use of (A)ATSR data in conjunction with geostationary data, such as that from SEVIRI, which would provide the diurnal variability signal, while the AATSR data would provide two “anchor-points” each day, which would serve to provide any necessary bias-correction to less well calibrated geostationary data. This procedure, which is already in use for SST fields (LeBorgne et al) is important for both climate monitoring and for model studies, as LST can be highly variable diurnally and so systems which do this accurately will be of high value. The combination of (A)ATSR and SEVIRI data has potential to achieve this.

Can (A)ATSR provide accurate LST data for use in climate research ?

The (A)ATSR series of data can provide a significant dataset for long-term studies although such datasets would need to be carefully considered in terms of time of day of the measurement, and corrections possibly applied. Large parts of the global land surface do not have temperature monitoring stations and so even regional analyses would vastly benefit from long-term satellite datasets.

The (A)ATSR datasets, particularly at night, are believed to have significant potential for accuracy. However, improved cloud screening, finer auxiliary data and better input climatologies for biome, fractional vegetation, emissivity and atmospheric parameters would help. Research into improved algorithms will also be of benefit.

How can (A)ATSR data be compared with relevant parameters from land surface models?

Land surface models are vital to a range of applications from regional weather to long-term climate as they are essential to understanding the driving of the hydrological and carbon cycles. LST data can provide a valuable constraint on the models and as such are highly desirable datasets. However, more research needs to be carried out on the differences between the LST-measured and the land surface model parameters since land surface models carry a number of parameters including canopy temperature, ground temperature and soil temperatures. Also the LST data and model resolutions may be quite different but more importantly model and reality may be different in terms of the type of surface or vegetation represented. Hence there is some important work to be carried out in integrating LST data with models.

Can (A)ATSR provide accurate surface albedo data for use in climate research?

Algorithms now exist which can retrieve both aerosol and surface reflectance from (A)ATSR data and indeed these have been applied offline to both ATSR-2 and AATSR data. These data should, after careful validation, provide excellent datasets for climate research. Both knowledge of aerosols and surface reflectance will enable scientists to diagnose such important phenomena as global “dimming” and “brightening” as well as other applications such as surface solar radiation.

How do the (A)ATSR Vegetation Index data compare with similar data from other sensors?

Vegetation and vegetation phenology are subjects of considerable interest and importance. These are climate change indicators themselves and are also significant in driving the influence of the land on weather and climate. A number of these indices exist and inter-comparison followed by combination would enable a very much increased sampling of the data, an important factor. (A)ATSR vegetation data would also make a very good contribution to the long-term time series of vegetation change. However, what needs to be used is atmospherically corrected (A)ATSR data to compute the vegetation index data as described above.

Can the detection of aerosol and clouds over land be achieved with comparable effectiveness to the ocean case, which will greatly improve the accuracy of land products such as NDVI and LST, as well as supporting many atmospheric science goals?

Cloud detection remains seminal to good performance of land surface products from (A)ATSR. Various methods exist for improving cloud detection, including cloud retrieval algorithms, and these need to have their performance quantified and improved as necessary.

Further details on aerosol and clouds products from (A)ATSR can be found in the next section.

3.4.3 Further remarks concerning (A)ATSR and land surface processes

The (A)ATSR series of instruments have the potential to greatly enhance our knowledge of the land surface and of its long-term evolution, in the way that (A)ATSR SST is greatly benefitting the climate community. As for SST, the (A)ATSR data will be used both directly and through other analyses (in which it will act as a reference sensor). Combination of MERIS data with (A)ATSR data may well yield further benefits in examining land surface processes. Until now, the (A)ATSR land potential has not been fully exploited so a renewed focus on applications in this area is much-needed and would be very timely.

3.4.4 Recommendations for future work

Recommendations for future work include:

1. A continued development effort for LST to produce accurate data for exploitation

2. Development of a GHRSST-like LST project which produces LST data for exploitation in a stripped-down format and with internationally agreed quality flags.

3. Exploitation of (A)ATSR data in combination with geostationary sensors to produce diurnal datasets with good reference calibration.

4. Development of an atmospherically-corrected vegetation index dataset

5. Inter-comparison of vegetation datasets from (A)ATSR and other satellite sensors exploiting, where possible, higher spatial resolution and other sampling characteristics of the various sensors involved. This recommendation is closely linked to 2 (above).

6. Performance of a critical assessment of available techniques for cloud detection over land and support to the development of possible approaches to this difficult problem.

3.5 The atmosphere

The (A)ATSR data have a huge potential to study both long-term changes in the atmosphere and to look at atmospheric processes. This potential is derived both from the possibility of using (A)ATSR aerosol and cloud information but also from the use of SST and LST data in models that drive atmospheric change. For example, it is well know that SST has considerable influence on meteorology and rainfall including the monsoon, on hurricane development, and on convection. These aspects of surface temperature and vegetation can be found in the sections above and the implications for atmosphere research will be outlined in future versions of the AEP.

This current version of the AEP concentrates on aerosols; for which there has been considerable recent activity in ESA and national programmes. It should be noted that cloud properties are also a significant strength of (A)ATSR and further development of the product and its exploitation are a clear need. Tropospheric water vapour columns are a key output for remote sensing instruments and (A)ATSR instruments have the potential to liberate such datasets, although uncertainty budgets need to be better understood. For these datasets, as for SST and LST, the relative quality of calibration for (A)ATSR data (including visible channels) is one of the strengths of the long-term data record.

In addition to direct atmosphere products, it is clear that (A)ATSR's other products are of considerable relevance for atmosphere studies: SST, fires, LST and changes in land cover. In the case of SST, the chief effects are on troposphere circulation including convection, resulting in influences on convection, precipitation and transport of heat in the atmosphere, and on heat fluxes. Recent research also indicates that trends and spatial structure of SSTs can play a significant role on transport into the stratosphere, and potentially on the subsequent evolution of the middle atmosphere dynamics. In the case of LST and fires, release of gases into the atmosphere represents a major component of the trace gas budgets for many species ranging from carbon dioxide and carbon monoxide to a range of organic compounds. These gases subsequently play significant roles in direct and indirect radiative forcing of climate, and in tropospheric chemistry and pollution. Hence the products described in earlier sections are also important for atmosphere studies.

3.5.1 What are the strategic scientific issues?

Aerosols are important in various scientific disciplines, such as radiative transfer, cloud formation, air quality, visibility, atmospheric stability, the hydrological cycle, human health and, in particular, climate change. Since the concept of aerosol-radiation-climate interactions was first proposed around 1970, substantial progress has been made in determining the mechanisms and magnitudes of these interactions, particularly in the last ten years. In recent years, the characterization of aerosols has been significantly improved through intensive field experiments, ground-based network measurements, and satellite remote sensing and its integration with model simulations.

Aerosols play important roles in the atmosphere, and can cause both positive and negative radiative forcing:

- They scatter and absorb sunlight, altering the amount of solar radiation reaching the Earth's surface (direct radiative forcing);
- They act as Cloud Condensation Nuclei (CCN) thus increasing cloud droplet concentration and therefore affect cloud albedo (indirect radiative forcing) and precipitation formation (a second indirect affect);
- They are involved in heterogeneous chemical reactions;
- They can lead to heating of the lower atmosphere if they contain light absorbers.

However, the global effect of aerosols is a reduction in the amount of radiation reaching the Earth's surface by -0.5 to -2.5 Wm^{-2}, which is comparable in magnitude with the positive forcing of +2.0 to +2.5 Wm^{-2} caused by greenhouse gases.

The IPCC recognises that the role of aerosols in climate is one of the largest uncertainties in our understanding of the present climate system and in our abilities to predict future climate change. The mechanism of aerosol direct effect is more difficult due to spatial and temporal aerosol variability. Large uncertainties also exist in current estimates of aerosol forcing because of incomplete knowledge concerning the distribution, and the physical and chemical properties, of aerosols as well as aerosol-cloud interactions.

Anthropogenic aerosols enhance scattering and absorption of solar radiation. They also produce brighter clouds that are less efficient at releasing precipitation. These in turn lead to large reductions in the amount of solar irradiance reaching Earth's surface, a corresponding increase in solar heating of the atmosphere, changes in the atmospheric temperature structure, suppression of rainfall, and less efficient removal of pollutants. These aerosol effects can lead to a weaker hydrological cycle, which connects directly to availability and quality of fresh water, a major environmental issue in the 21st century. Indirect effects of aerosols on clouds remain an enormous challenge from both the observational and modelling perspectives. Only recently have studies been focused on estimation of the indirect radiative forcing of aerosols, as a result of the improvement of satellite and modelling techniques. ATSR-2 data have been used for this very purpose.

Visibility loss caused by aerosols is also an issue. This is primarily due to suspended airborne particles, which scatter light efficiently, giving the atmosphere a 'hazy' appearance. In addition to visibility and climate implications, these particles have significant health impacts which have been increasingly recognized. Aerosols have been linked to many health problems affecting allergy sufferers and those with respiratory conditions like asthma and emphysema. In light of many recent studies, there now exists overwhelming scientific evidence that inhaled aerosols increase the risk of respiratory and cardiopulmonary disease. While it is accepted that the concentration of aerosols is a factor in the incidences of these conditions, the effect of specific aerosol properties such as type, size, and spatial and temporal distribution are not well known.

It is evident that there are numerous strategic scientific issues which need to be addressed regarding aerosols and clouds. The 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, due to a high spatial and temporal variability of aerosol loading. The complicated links between aerosols and cloud properties mean that, the total aerosol forcing of the climate system remains quite uncertain. In addition to global climate, aerosols affect the climate of specific regions and their water cycle.

It is generally accepted that our knowledge of cloud dynamic and radiative properties falls well short of that required by modern climate analyses and prediction schemes. Due to the many different aerosol sources and their short lifetimes, tropospheric aerosols are highly variable in both space and time. Remote sensing is the only means capable of providing global observational aerosol data that are needed for assessing direct and indirect aerosol effects.

What is the anthropogenic component to aerosols and how will this change with time?

Aerosols can be classified as primary and secondary aerosols based on the source and chemical reactions. They can be directly emitted as particles (primary aerosols) into the atmosphere by volcanoes, through the effect of wind lifting dust particles in arid regions, from combustion during biomass burning, from sea spray, from vegetation etc, or can be derived from living organisms. They can also be the result of chemical reactions, in particular gas-to-particle conversion (secondary aerosols). Anthropogenic sources contribute significantly to atmospheric aerosols (particularly water soluble aerosols). This is likely to increase with rising global populations.

What are the effects of aerosols on atmospheric stability?

Absorbing aerosols, such as elemental carbon, which strongly absorbs visible light, or mineral dusts, which absorb long-wavelength infrared, can lead to heating of the lower atmosphere.

This changes the differential heating of the atmosphere and therefore atmospheric stability, which in turn influences convective and turbulent motions and cloud development.

What are the effects of aerosols on cloudiness?

Aerosols act as CCN when water vapour condenses onto aerosols to form cloud droplets in a process known as heterogeneous nucleation. Aerosols therefore modify cloud droplet growth, which affects cloudiness and precipitation in both magnitude and location. This aerosol-cloud interaction can play a significant role in both the direct radiative balance of the atmosphere and in the hydrological cycle. The implications for both the understanding and prediction of future climate change are significant.

What are the effects of pollutant aerosols on cloud particle formation over populated regions?

Activation of CCN is one of the most important processes in cloud and rain formation. To form raindrops, cloud particles have to increase in mass more than a million times and these cloud particles are nucleated by aerosols with a radius as small as 0.01 μm. It has been hypothesised that high concentrations of small 'pollutant' aerosols (Aiken nuclei) reduce the effective droplet size and increase cloud albedo for a constant amount of liquid water. These high concentrations can narrow the droplet size distribution and prolong the lifetime of clouds, especially over urbanised regions.

What are the effects of aerosol on precipitation and hence the hydrological cycle?

Different aerosols can have different impacts upon precipitation. Small aerosols that cause a narrowing of the size distribution of cloud droplets lead to reduced or suppressed precipitation, since a range of droplet sizes are required for warm rain to develop. In polluted clouds it is suggested that there are too many small droplets and not enough larger or 'giant' droplets. However, it has recently been suggested that due to reduced collection efficiency, such clouds may continue to ascend to altitudes where graupel and ice crystals form – these clouds are deeper and produce heavy rain, lightening and hail. Therefore, under certain conditions, a delay in the onset of warm rain due to aerosols can result in delayed downdraft formation, allowing for a more invigorated updraft which produces deeper and stronger convection. For example, this effect may be experienced 'downwind' of urbanised regions.

In contrast, the presence of 'giant' nuclei can act to enhance precipitation. Giant aerosols produce large cloud droplets near the cloud base – the effects of such giant CCN are significant when the concentration of small, Aitken nuclei is high, as in urban clouds. Giant CCN act as a destabilising factor, by accelerating collisions and coalescence between the water drops, which causes early development of large drops in lower parts of the cloud. Furthermore, giant CCN accelerate precipitation formation through the ice phase, due to formation of ice by nucleation. Large droplets formed by the giant CCN produce graupel particles earlier – these have high coagulation efficiency with drops and therefore grow more rapidly as they are lifted in the updraft region, yet they remain close to the cloud base which can also promote ice multiplication processes in supercooled regions.

Aerosols clearly have huge impacts on the precipitation process, and can either enhance or suppress precipitation depending upon type of aerosol, seasonality, climate regime, cloud type or orographic profile of a region, particularly over populated areas.

How do aerosol-cloud interactions modify the visible shortwave spectrum and hence the radiation balance of the Earth?

Atmospheric aerosols can scatter, absorb and emit electromagnetic radiation. They influence the radiative budget in two ways, firstly by backscattering incoming solar radiation, and secondly by changing the albedo and lifetime of clouds. The interactions between aerosols and solar radiation are therefore determined by a combination of aerosol properties, surface properties, clouds, and geographical parameters.

When molecules within the atmosphere are smaller than the wavelength of visible light, light is scattered by these molecules. Light at the shortest wavelengths is scattered preferentially, resulting in a blue hue to the sky. Equal amounts of light are scattered both in forwards and backwards directions. This scattering is termed Rayleigh scattering. Mie scattering occurs within the atmosphere when particles or droplets are similar or slightly larger than the wavelength of the incident light. Mie scattering is not strongly wavelength dependent and produces the almost white glare around the sun when a lot of particulate material is present in the air. Because of their diversity, aerosol particles have a wide range of sizes. However, the aerosols most important for optical scattering, and cloud droplets, are comparable to visible wavelengths. The direct and indirect effect of aerosols is to decrease the amount of energy reaching the surface.

Most of the aerosol particles are so weakly absorbing that their extinction is almost entirely due to scattering, rather than absorption. However, soot (carbon) particles are quite strong absorbers, and the absorption increases at short wavelengths. While this decreases the radiation flux at the surface, it heats the atmosphere locally. The heating can in turn cause a third climate forcing effect, known as the semi-direct radiative effect; the heating of the atmosphere can suppress the local relative humidity and thereby reduce cloud formation, which would have otherwise caused surface cooling, so the net effect is to increase the amount of energy reaching the surface.

3.5.2 How can (A)ATSR contribute?

Data from (A)ATSR have been used to deduce water vapour content of the atmosphere on a global basis. This is possible because the atmospheric correction process intrinsically estimates water vapour absorption and emission. The feasibility of generating water vapour fields has been demonstrated but the technique has not yet been subjected to rigorous evaluation or to critical comparison with other available techniques. However, it must be borne in mind that the (A)ATSR channels are not well suited to detection of other atmospheric constituents, in fact they are specifically chosen to avoid or minimise atmospheric absorption.

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 (A)ATSR's multi-angle multi-wavelength viewing geometry to characterise and investigate the properties of clouds. The (A)ATSR, on account of its unique dual angle viewing geometry, is especially sensitive to atmospheric aerosol and there is great potential for using (A)ATSR data, generally in combination with data from other sources, to examine and quantify the radiative properties of atmospheric aerosols.

All seven (A)ATSR channels, extending from approximately half a micron to 12 microns in wavelength, are very well matched to aerosol sizes and therefore (A)ATSR has great potential for the detection of atmospheric aerosols and the measurement of various key parameters such as size and concentration. This potential is currently being vigorously explored in several ways, which will be described and discussed in this section.

Can (A)ATSR provide information on cloud and aerosol microphysics by utilising its range of spectral channels?

Aerosols influence both the visible and infra-red channels of the (A)ATSR instruments, with larger effects in the forward than in the nadir view. The challenges of aerosol retrieval are such that current global algorithms tend to use nadir-only views of the visible channels. More restricted applications on regional scales have also shown the benefits of utilising the dual and forward views but considerable care is required over land. Further possibilities to differentiate large particle sources, such as Saharan dust, using the infra-red channels increase the likely success of differentiating aerosol types with (A)ATSR data.

Future and current climate simulations, using state-of-the-art models, are very sensitive to changes in the current cloud parameterisation schemes. Indeed, models can even introduce compensating errors that hide additional sensitivities to certain parameters. Accordingly, the scientific community has put an imperative on the validation of these cloud parameterisations by confronting the model simulations with observations. While high-resolution measurements obtained in experimental campaigns are necessary to develop the parameterisations, the evaluation of model cloudiness requires comparison with global climatological data. Such climatological comparisons can highlight specific areas of disagreement, but do not always explain the reasons why the observations and models disagree as other model problems can manifest in the simulated cloudiness.

For comparison with climate models, observational studies that are restricted seasonally and/or spatially to identify specific synoptic regimes are becoming more important. Despite the apparent proliferation of cloud data, the information about cloud properties is often limited to frequency information and optical thickness along with environmental data (e.g. cloud top temperature and pressure). While there is relatively good agreement in some cases between sensors for gross measures of cloudiness (e.g. seasonal and zonal means) there is still considerable disagreement in detail.

Long-term global datasets of cloud optical and physical parameters are essential. The required long-term cloud data can be obtained from the long-term dataset of visible reflectances from 1995 until the present day, from ATSR-2 and AATSR. Several different algorithms have been developed over the years and one of these forms the basis of the GRAPE project that has initially analysed the ATSR-2 dataset with future data from the AATSR to be added at a later stage. The GRAPE project has produced a new cloud database which will include the following parameters, along with associated error measurements (enabling the use of these data in some form of data assimilation at a later date):

- Cloud Optical Depth
- Cloud Phase
- Cloud Particle Size
- Cloud Top Pressure
- Cloud Fraction
- Cloud Water Path

Can (A)ATSR cloud data deliver information on trends in cirrus cloud occurrence or distributions?

High-level cirrus has a strong influence on Earth's radiation budget. Cloud detection tests are implemented as part of the (A)ATSR processing. (A)ATSR features 7 spectral channels, including a 1.6 micron together with a 54 degree forward view, which allows improved distinction to be made between low level water clouds and high level ice clouds. The brightness temperature (BT) difference between 11 μm and 12 μm channels is large over thin cirrus due to differences in emissivity at these wavelengths and can therefore be used to provide information on cirrus. Contrails and resulting cirrus clouds also have significant climate impacts – a contrail detection algorithm (CDA) has been successfully used with (A)ATSR data. The GRAPE project also covers inter-hemispheric difference in cirrus. Studies of cloud data have also indicated that the effects of ship-tracks can be identified in (A)ATSR data (see below)

Can the (A)ATSR series provide a long time series of global aerosol data which can indicate time trends and regional developments in aerosol loading of the troposphere and hence its impact on climate?

(A)ATSR instruments have provided a long-term record of accurate estimates of aerosol properties at regional and global scales since the start of the ATSR-2 mission in 1995. Aerosol retrievals are undertaken using a method of optimal estimation, which has been well validated. The aerosol algorithm uses four spectral bands (0.55, 0.66, 0.87, 1.6 μm) for retrievals of aerosol optical depth (AOD), effective radius and surface albedo. These data can be use to used to examine and quantify the radiative impacts of atmospheric aerosols, and the effects of regional and temporal variations in aerosol loading on climate.

What is the relationship between (A)ATSR derived aerosol optical depth measurements and air quality parameters such as PM2.5 and PM10?

AOD is the optical depth due to extinction by the aerosol component of the atmosphere – it can be used as a proxy for ground-level particulate matter concentrations, and thus air quality. AOD can be determined from the ground through measurements of the spectral transmission of solar radiation through the atmosphere using an instrument pointed directly at the sun called a sun photometer or filter radiometer. The spectral behaviour of the AOD depends strongly on the aerosol size distribution. A unique feature of the (A)ATSR is the dual-view capability providing two views of each region: first a forward view and about two minutes later a nadir view. Using a dual or a multiple-angle view of the same scene (at nearly the same time) should significantly improve the accuracy of the satellite AOD retrieval. (A)ATSR AOD retrieval algorithms show good comparison with other satellite retrievals (e.g. GOME, AVHRR, MERIS, SCHIAMACHY), and with aircraft and ground-based measurements (AERONET).

What do (A)ATSR measurements tell us about the regional background of aerosols, and hence regional air quality and its evolution during anticyclonic summer heat waves and winter freezing episodes?

At a regional level, atmospheric aerosols are influenced by the synoptic situation. For example, the characteristics associated with heat wave development can strongly affect the regional atmospheric aerosol properties. Anticyclonic summer heat waves result in the accumulation of pollutants, increased forest fires, and induced high ozone and particulate matter levels. This is due to high temperature and radiation, stagnation of air masses and weak dry deposition, which favour accumulations. Similarly, winter freezing episodes also result from anticyclonic circulations – this type of circulation is favourable to the long-range transport of aerosols (sinking air and gentle winds). Coefficients adopted for background tropospheric aerosols have been included in the 'atmospheres' used to develop the (A)ATSR retrievals. (A)ATSR can therefore provide information on background aerosols and variations in air quality during such events.

Can (A)ATSR provide information on the transport of mineral dust that affects the growth of phytoplankton?

Saharan dust aerosol particles are relatively large (e.g. several μm) and are transported in the troposphere, typically at heights of 1.5 to 4.5 km. The transport of the dust can also be associated with unusually high atmospheric temperature and low relative humidity, which have been traced as far as the Caribbean. Previous work has shown that (A)ATSR can provide information regarding the transport of mineral dust – for example, aerosol plumes have been identified over the Sahel and Southern Sahara region by using the 0.55 μm band in the forward direction (the forward view is more sensitive to atmospheric scattering due to the longer path length).

Can (A)ATSR aerosol data be employed to indicate long range transport of aerosols in the troposphere?

(A)ATSR could be used, in conjunction with back-trajectory analysis, to investigate the source of long-range aerosol plumes. As discussed above, (A)ATSR can also be used to examine the transport of large aerosol plumes, such as those originating in the Sahel. Furthermore, (A)ATSR fire maps could be used to help document the spatial extent of rainforest fires and to identify the air masses containing the smoke aerosols.

Can (A)ATSR data be employed to monitor stratospheric aerosol following major volcanic eruptions, thus providing essential information for the ozone layer and surface sensing communities?

As discussed previously, identifying the presence of aerosols in order to accurately retrieve surface temperature is a practical priority. The eruption of Mount Pinatubo in 1991, first demonstrated the impact of stratospheric aerosols on SST retrievals, and the potential for using (A)ATSR to examine aerosols.

Stratospheric aerosols, such as those released during volcanic eruptions, provide a surface where the ozone destruction reactions take place very rapidly. It has also been observed that it takes much longer for aerosols to be removed from polar regions than from tropical regions. (A)ATSR retrievals of stratospheric aerosols (i.e. anomalies, atmospheric lifetime), especially over polar regions, could therefore provide essential information regarding ozone depletion.

Can (A)ATSR data quantify radiative forcing due to exceptional aerosol events?

(A)ATSR data can be used to quantify the aerosol forcing of specific events. For example, previous work has used (A)ATSR data to derive a global distribution of ship tracks and estimate their radiative forcing using backscattered radiation at the top of the atmosphere (TOA). The ship tracks result from the emission of aerosols from ships into the clean marine boundary layer, which alters cloud reflectance. With good discrimination of aerosol types, synergistic studies with radiation budget experiments should be possible.

3.5.3 Further remarks concerning (A)ATSR and the atmosphere

It has been stated that, in contrast to the detection of molecular constituents, which (A)ATSR is designed to avoid, (A)ATSR has strong potential for cloud and aerosol measurements. The climatic importance of these atmospheric components is now recognised as very great and a significant number of very different satellite sensors are now being used to retrieve aerosol properties. There is little doubt that most of the techniques for their measurement are, in every case, fraught with difficulty, largely on account of the spatial and temporal variability of their distributions combined with a large number of physical parameters which determine their radiative properties. For these reasons, it is important that techniques for using AATSR data for the detection and measurement of aerosol and cloud properties are given high priority. Particularly, those techniques that work well over land and at night are important because relatively few other sensors are able to give useful information in those conditions.

In common with the more developed (A)ATSR products such as SST, high quality internal verification and independent validation results are important. Networks such as Aeronet provide an obvious platform for comparisons but more detailed analyses will be required over time and care will be needed to ensure key regions and continents are strongly addressed.

3.5.4 Recommendations for future work

For aerosol data, the following steps are recommended:

1. Careful regional validation/characterisation of the aerosol data should be performed, including aerosol properties such as type and radius.

2. The use of (A)ATSR aerosol data should be promoted to users, along with very good information on the quality of the data and training in its use.

3. The combination of (A)ATSR aerosol data with other appropriate datasets such as MODIS or MERIS aerosol should be investigated.

4. The development of operational (A)ATSR aerosol and cloud products should be supported and implemented.

5. The use of (A)ATSR aerosol data for climatological air quality studies should be investigated.

3.6 The cryosphere

3.6.1 What are the strategic scientific issues?

The (A)ATSR series of instrument provide frequent observations of the Arctic and Antarctic region. Information from these observations can be used for qualitative physical monitoring of icebergs, providing information on their spatial distribution, of their calving, breakage and melt rates, and of their movement. These icebergs represent a major component of the mass discharge from the both the Greenland and Antarctic ice sheets, and hence of the overall mass budget of the ice sheet. In addition, images from the (A)ATSR series can be used for long-term monitoring of sea ice extent. Such information is an important input to the many climate change scenarios. However, AATSR data have a rather narrow swath-width and cloud-cover provides a major limitation. For this reason users have so far placed little emphasis on the use of AATSR data in the cryosphere.

3.6.2 How can (A)ATSR contribute?

Despite the limits of coverage and cloud obscuration, AATSR data has one important feature for cryospheric studies, this is the 1.6 micron wavelength reflected channel, which is not featured on many other satellite sensors. This channel has the potential to distinguish well between water and ice and between different ice-types. Also the (A)ATSR channels can provide some good discrimination between snow and cloud, a property which is beginning to be exploited.

3.6.3 Further remarks concerning (A)ATSR and the cryosphere

It should be noted that remarkable SST data were obtained from AATSR in Arctic waters during the summer of 2007, when extraordinarily high SST anomalies were observed and ice had retreated by record amounts. In the future, increased attention is bound to be paid to SSTs in the summer Arctic waters and, as the ice-cap is breaking up, good techniques for detecting ice contamination in SST pixels will need to be refined. The 1.6 micron channel will undoubtedly find a role here

3.6.4 Recommendations for future work

1. Carry out a critical assessment of the potential of the 1.6 micron and other channels to distinguish between ice, snow, water, cloud and between different ice-types

2. Develop schemes for detecting fractional ice contamination of otherwise clearly visible Arctic waters

3. Examine the long-term record of SST, sea ice and cloud in the (A)ATSR record.

4 OPERATIONAL APPLICATIONS

4.1 Introduction

This section describes operational services using (A)ATSR data. The section includes a brief description of the highly successful GODAE High Resolution SST Pilot Project (GHRSST-PP), which has developed the basis for what is now an operational service (although it is based on a pre-operational satellite, Envisat). This section also describes in outline the operational services now being put in place within the GMES programme.

4.2 Operational applications and the OSTIA SST analysis

4.2.1 GHRSST-PP and Medspiration

During the past two years, the operational use of (A)ATSR data has taken a major step forward as a result of the ESA-funded Medspiration project, which has formed the European backbone of the international GHRSST-PP. This highly successful series of initiatives has produced a new generation of global NRT SST data.

GHRSST-PP has developed and introduced a new format, Level 2P, which is based on the standard ESA gridded level 2 SST products and which is especially tailored to the needs of operational users. The L2P format is based on NetCDF and, most importantly, includes Single Sensor Error Statistics (SSES). This innovation means that confidence flags can be derived on a pixel-by-pixel basis, thereby giving operational users an automatic means of deriving appropriate weight to data as they are ingested. The (A)ATSR SSES are particularly sophisticated and effective on account of the fact that (A)ATSR's unique dual view, when compared to the single view, provides a quantitative and independent indication of data quality. The L2P format also has the ability to include data from both satellite and *in situ* sources.

Medspiration is an ESA-funded Data User Element (DUE) project which constitutes the European element of GHRSST-PP. Medspiration has led to the parallel generation of SST data streams, in L2P format and from several satellite and *in situ* sources. Both Medspiration and GHRSST-PP have been highly successful projects, especially when considered in combination, which have led to operational exploitation of (A)ATSR data and SST data from other sources.

As a result of the GHRSST-PP, meteorological services in Europe and USA have been using and evaluating (A)ATSR data. A consensus view is now emerging that (A)ATSR data, although offering less coverage than other sensors, are the most accurate available and can be used in multi-sensor analysis schemes as the benchmark against which data from other sensors can be bias-corrected. (A)ATSR data are now used in operational NWP services from both the UK Met Office and ECMWF. This is done via the OSTIA analysis (see next section), of which (A)ATSR is a fundamental and the most accurate element. This has arguably been the most significant development in the exploitation of (A)ATSR data to date.

4.2.2 The OSTIA analysis

The Operational SST and Sea Ice Analysis (OSTIA) is a daily analysis scheme developed and operated by the UK Met Office. Its main product is a daily global SST field derived from a variety of satellite and *in situ* sources, principally those serviced by the GHRSST-PP programme, where the data are delivered with error statistics. Full details of OSTIA and the various products and analysis functions it provides, can be seen at:

http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html

In 2007, the OSTIA SST Analysis underwent evaluation by the UK Met Office and was subsequently incorporated into the daily NWP process, where its impact has so far been positive. On the basis of this experience, ECMWF also use OSTIA in that way. Thus, as a result of the GHRSST and Medspiration initiatives, AATSR data have acquired operational status.

4.3 The EU GMES programme

4.3.1 Objectives of the GMES programme

The over-arching objective of the European Union (EU) programme for Global Monitoring for Environment and Security (GMES) is to establish and promote "a concerted effort to bring data and information providers together with users, so they can better understand each other and make environmental and security-related information available to the people who need it, through enhanced or new services."

Further details are obtainable from http://www.gmes.info/.

There are two main elements of the GMES programme in its current state of evolution:

1. The space observation segment, initially funded by ESA and consisting of a series of Sentinel satellites.
2. The Core Service Elements, funded by the EU under FP7.

These are described briefly below.

4.2.2 The Sentinel-3 mission and SST

The Sentinel-3 mission is to make ocean observations of temperature, topography and colour. It also has objectives over land, which includes measurements of vegetation cover and LST. SST is to be measured by a new dual-view scanning instrument, currently designated the Sea and Land Surface Temperature Radiometer (SLSTR). This instrument is required to have all the attributes and qualities of (A)ATSR, with some additional requirements to cater for the needs of other users, such as a wider swath-width and co-registration with other sensors on-board Sentinel-3. The SLSTR is more complex than (A)ATSR and it will be important to ensure that true data continuity is maintained as the programme develops.

4.2.3 MyOcean

MyOcean is a Framework 7 programme of the EU that implements the Marine Core Services element of GMES. It is led by Météo France and will run initially for three years from January 2009. The part of MyOcean which deals with SST data is called the SST Thematic Assembly Centre (SST TAC), which is also based at Météo France. My Ocean is described at:

http://ec.europa.eu/enterprise/space_research/core_products_and_services/marine.htm

4.4 Further remarks concerning (A)ATSR and operational applications

The strong growth in operational utilisation of (A)ATSR data is a new, in some ways unexpected but very welcome development for AATSR, but one which is extremely successful, as new international users (e.g. Météo France, Deutsche Wetter Dienst and ECMWF, as well as US agencies) are now using or planning to use OSTIA in their NWP systems. The inclusion of AATSR data in a daily multi-sensor analysis provides users with the complementary advantages of the available sensors, combined with the especially high accuracy of AATSR. This is a particularly important step forward when considering the huge advantages of coverage offered by microwave and/or geostationary sensors, for which calibration has always been a troublesome issue - as, indeed, the narrow swath of AATSR has always been seen as a major limitation for certain types of investigation and monitoring.

The success of the GHRSST project for SST suggests that a similar project for LST would yield significant user uptake. Interactions with the user community for land surface and climate information, suggests that the increase in interest and need for LST information is growing rapidly. Therefore it would be timely to consider a Medspiration-style DUE project as part of a commitment to a wide GHRSST-type project for land surface temperature.

4.5 Recommendations for further work

The most important next step is to make more precise quantitative assessments of the impacts upon the accuracy of OSTIA and, eventually, on the NWP performance, of AATSR when it is included into OSTIA. This would require the use of OSTIA in experimental mode, which may be difficult to arrange as it is embedded in operational activities. However, ways of doing this need to be pursued, in collaboration, of course, with meteorological agencies,

Hence recommendations for future work:

1. Quantification of the impact of AATSR data on the accuracy of OSTIA
2. Assessment of the impact of AATSR data on ocean model assimilation schemes via OSTIA.
3. Promotion of AATSR data to other meteorological services for similar applications.
4. Support for an international GHRSST-type project for LST with an associated DUE project.

5 UNDERPINNING ACTIVITIES

5.1 Overview

This section details important supporting activities needed to ensure the maximum scientific exploitation of (A)ATSR data. These include the need:

- to accurately and continuously calibrate the instruments in-orbit
- to validate (A)ATSR products on the ground accurately and continuously
- to improve the existing (A)ATSR algorithms and develop new ones
- to ensure timely and effective delivery of (A)ATSR data products to users
- to ensure continuity of (A)ATSR data products for long-term monitoring

The following sections will consider each of these in turn.

5.2 Calibration and validation

The ATSR instruments include two well calibrated onboard blackbodies that are maintained at the warm and cold limits of the SST range observed by the instrument. Both blackbodies are observed on each instrument scan thereby enabling the stability of the infrared channels to be checked constantly by the Flight Operations Support (FOS) team on the ground. In addition, a VISCAL system is used to calibrate the visible channels once per orbit. The flight data can be compared with the reference data measured during the pre-launch calibration activity performed with specialised equipment at RAL. Both the calibration data measured on the ground and the continuously supplied calibration data from the instrument are essential for the maintenance of the accuracy of the instrument measurement data.

The accuracy of the algorithms and processing software that produces the Level 2 products, including SST and LST, is checked by comparing the L2 datasets with *in situ* data gathered by the (A)ATSR validation team, for example using ship-borne radiometers such as ISAR. Long-term, continuous validation is essential to track potential changes in the instrument performance and to detect small deviations between the instrument and *in situ* measurements. Analyses of these differences lead to improvements in algorithms and data processing. Thus ongoing *in situ* validation programmes are essential components of the (A)ATSR programme.

In the future, this validation activity will become ever more important. The use of (A)ATSR data for climate and operational applications requires quite different approaches with relative bias and trends with time being important for the former, and good error and quality control/assurance schemes being important for the latter. Both are, however, mandatory (as recognised by the QA4EO process) and it will be important for the validation programme, supported by the PI team, to undertake consistent and vigorous validation studies of products. This programme should be supported by a formal process for recognising products as “official” (A)ATSR datasets.

5.3 Algorithm development

It is of the highest importance that the scientific bases for the SST and other product retrieval schemes is the continued subject of critical ongoing investigation in order to ensure that (A)ATSR retrievals remain the best that can be achieved. As described in the section above, data produced from these algorithms can be tested to elucidate their real performance. In addition, proposed “products” should be assessed in a theoretical framework with assessment of errors.

Currently, major innovations in algorithms are taking place with respect to the standard operational products, such as SST, and the developing products, such as aerosols. These include optimal estimation techniques, cloud detection systems, surface reflectance prescriptions (allowing dual-view retrievals over land) and joint retrievals from the visible and thermal channels combined. These developments are very welcome and should lead to realisation of the full potential of (A)ATSR data. Detailed investigations of product improvements and data verification activities will run alongside these activities, and some resource will need to be devoted to “operational” implementations.

5.4 Data delivery

Ready availability of the (A)ATSR data products is essential if the data are to be used by scientists and operational users. The data need to be provided in NRT to operational users and also as reanalysis products for scientific users. Whilst the accuracy of the NRT data need not be perfect, it is important for applications such as climate change research, that the data is as accurate as possible. This involves both using consolidated product data with restituted orbit data and frequent (roughly yearly) reprocessing of the entire dataset with the latest algorithms.

This activity involves the operation and maintenance of both an NRT system and a reference long-term archive, with regular reprocessing of the entire reference dataset. In addition, there needs to be a mechanism to ensure that the entire (A)ATSR record can be processed with due diligence but also timeliness, as products improve and change. This is particularly important to meet the timescales anticipated for the IPCC (for work to be considered, papers should be submitted to journals by March 2011).

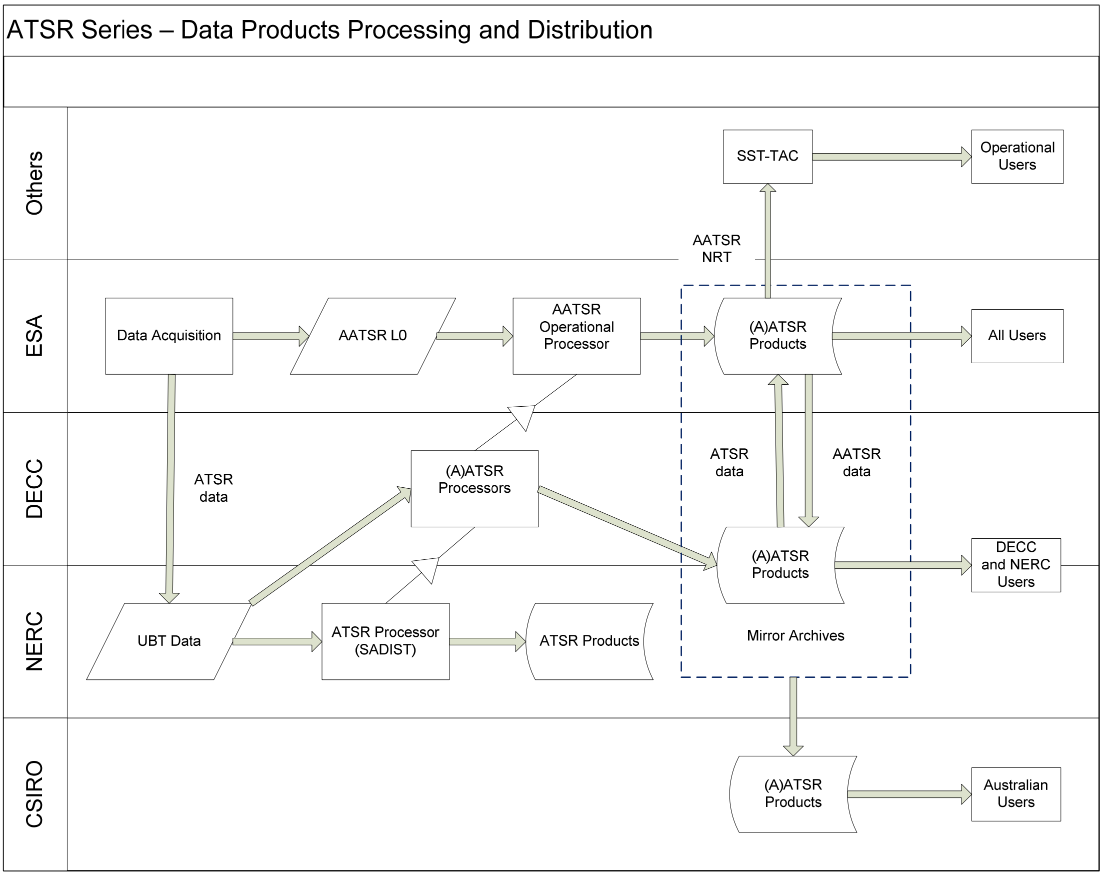

Figure 5-1: (A)ATSR data flows

One of the aspects that will be the key to user exploitation will be the interface to the archive. It is recommended that close attention be made to the ability of users to access and interface easily with data for the purposes of, for example:

1. comparison to ocean model data and SST analyses
2. case studies e.g. coastal waters.

Many of the tools are in place but a one-stop shop interface with “easy access” procedures should be considered.

5.5 Data continuity

An important objective of (A)ATSR is to establish continuity of the high-precision record of global SST initiated by the ATSR sensor in 1991 and continued by ATSR-2 and AATSR. The (A)ATSR sensors thereby provide an 18 year dataset (through June 2009) for quantitative investigation of global climate change.

Two 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 that they achieve the highest levels of possible accuracy and secondly, there is a need to ensure that the stability and consistency of the data products is maintained throughout the dataset, even if this requires regular re-processing of the entire dataset in response to refinements in the retrieval procedures that will always emerge from a vigorous and pro-active research programme. Clearly, these priorities represent an imperative for a detailed assessment of the accuracy and validity of the (A)ATSR data products, requiring long-term validation of the data.

The needs for both long-term climate records and for operational data flows to support operational oceanography are key drivers for an SST measuring instrument on Sentinel-3. It is important that such a mission be flown but also crucial that the performance of this successor system be maintained to AATSR standards. The areas of exploitation outlined in this document will be as important for Sentinel-3 as for three (A)ATSR instruments and indeed the wide swath implementation of SST will be enable many of these applications to be met in a more substantial manner.

5.6 Adherence to GCOS Climate Monitoring Principles

The ten basic principles were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. The complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.

The way in which the (A)ATSR exploitation programme adheres to these principle is interspersed with the principles in the text below.

Effective monitoring systems for climate should adhere to the following principles:

1. *The impact of new systems or changes to existing systems should be assessed prior to implementation.*

   The design of SLSTR meets the science and instrument performance requirements of AATSR in order to maintain the high quality of SST measurements. In addition, the design of the SLSTR processing algorithms is taking full account of the need for continuity with the (A)ATSR archive.

2. *A suitable period of overlap for new and old observing systems should be required.*

   Due to the time it has taken to formulate and approve the follow-on mission for AATSR, it is likely that there will be a gap between AATSR and SLSTR. In an attempt to close this gap, the Envisat mission is adopting a fuel-saving scenario to extend the mission beyond 2010. The intention is to avoid future gaps by launching a series of overlapping Sentinel-3 missions, so that there should always be at least one working SLSTR in orbit at any one time, and nominally two to increase coverage and enhance its operational uses.

3. *The results of calibration, validation and data homogeneity assessments, and assessments of algorithm changes, should be treated with the same care as data.*

   The QWG maintains oversight of calibration, validation and data homogeneity, and algorithm changes. All changes to the existing (A)ATSR data products that takes into account validation issues and algorithm improvements are implanted in a controlled manner so that the integrity of the (A)ATSR archive is preserved.

4. *A capacity to routinely assess the quality and homogeneity of data on extreme events, including high-resolution data and related descriptive information, should be ensured.*

   The QWG, supported by the ESA IDEAS team and the DECC DEC team provides the means for routinely monitoring the quality and homogeneity of the data in all circumstances.

5. *Consideration of environmental climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.*

   One of the main users of the AATSR data is the UK Met Office, which uses the SST data in its climate models that contribute to the IPCC process. The Met Office requirements are a key driver for the mission and the reason DECC funded the AATSR instrument.

6. *Uninterrupted station operations and observing systems should be maintained.*

   ESA maintains a network of ground stations and an on orbit data relay satellite (Artemis) to achieve 100% coverage of the Envisat mission.

7. *A high priority should be given to additional observations in data-poor regions and regions sensitive to change.*

   The PI, SAG and VS advise the funding parties on regions that they consider to be most sensitive to climate change in order for the funding parties to prioritise their research spending in these areas. The AEB and the AEP provides a mechanism by which priorities can be identified and supported with the necessary funding.

8. *Long-term requirements should be specified to network designers, operators and instrument engineers at the outset of new system design and implementation.*

   This has been done for SLSTR and the Sentinel-3 mission.

9. *The carefully-planned conversion of research observing systems to long-term operations should be promoted.*

   This is being undertaken in an evolutionary way, first with the production of the GHRSTT L2P product as an official ESA product available to operational users via the SST-TAC, and also in the increase in nadir swath width of SLSTR relative to AATSR. Together with the deployment of tandem Sentinel-3 missions 180^{o} apart, this will increase the coverage of SST data to a level similar to AVHRR

10. *Data management systems that facilitate access, use and interpretation should be included as essential elements of climate monitoring systems.*

    ESA provide such a system for accessing the (A)ATSR archive. In addition, DECC, NERC and CSIRO users are able to access a mirror archive at the NEODC in the UK. The operation of parallel, identical archives provides resilience in processing data and providing products in a timely manner to users.

Furthermore, satellite systems for monitoring climate need to:

(a) *Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite crosscalibration of the full operational constellation a part of the operational satellite system; and*

    The ATSR series are self-calibrating instruments that are monitored by the design team at RAL in support of the flight operations team at ESOC. In addition, DECC funds scientific work at the University of Leicester to perform cross calibration of the sensors with other missions. The results of these exercises are available on the (A)ATSR websites and are published in peer-reviewed scientific papers.

(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

The ATSR series provides data that is sensed around an equatorial crossing time of 1030 a.m. These data can be used to monitor seasonal changes and long-term inter-annual changes. (A)ATSR data can be also be used as a reference dataset to improve the diurnal data produced at lower resolution by instruments on geostationary satellites such as SEVIRI on Meteosat.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained.

The ATSR series is operated on spacecraft that have well-controlled attitudes and orbits, so that a consistent equatorial crossing time is maintained. The Sentinel-3 spacecraft will adopt the same crossing time.

12. A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations.

Such overlaps have been achieved between ATSR-1 and ATSR_2, and between ATSR-2 and AATSR. They have provided important information on the performance of all three radiometers. It is unlikely that an overlap between AATSR and SLSTR will occur but a scheme to tie the AATSR and SLSTR records to the same *in situ* radiometer record is under active consideration, in order to mitigate the effects that any gap may have on the long-term dataset.

13. Continuity of satellite measurements (i.e., elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured.

This is being addressed by extending the Envisat mission to the nominal start of the Sentinel-3 mission.

13. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured.

This is performed in the pre-flight calibration at RAL.

14. *On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored.*

    The on-board blackbodies are well characterised during ground tests and monitored on ever scan in orbit. Blackbody crossover checks are made every six months in orbit as an added check on the stability of the onboard calibration system.

15. *Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate.*

    SST is produced as a priority. New products, including LST and aerosol products are being introduced after being peer-reviewed by the SAG and other scientists.

16. *Data systems needed to facilitate user access to climate products, meta-data and raw data, including key data for delayed-mode analysis, should be established and maintained.*

    The ESA and DECC/NERC ground systems provide mechanisms for the provision of both near-real-time operational products and a climate-standard archive.

17. *Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites.*

    ERS-2 has been maintained well past its design life, although the scan mirror on ATSR-2 finally stopped working in February 2008. Similarly, Envisat will be operated well beyond its design lifetime in an attempt to bridge the gap with Sentinel-3.

18. *Complementary in situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation.*

    ESA and DECC both operate *in situ* radiometers (SISTeR and ISAR, respectively). ISAR is providing a near continuous long-term record (since 2003) to check the performance of AATSR. It is intended to continue this record to provide an overlap with SLSTR. In addition, measurements from ships and buoys are available to provide better coverage. These provide a longer-term record, albeit with greater errors than the *in situ* radiometer records.

19. *Random errors and time-dependent biases in satellite observations and derived products should be identified.*

DECC and ESA run science and validation programmes to investigate random and systematic errors in the observations, and provide recommendations on ways to improve the derived products.

5.7 Further remarks concerning underpinning activities

The underpinning activities are essential activities to monitor and improve (A)ATSR data product quality. At the core of this effort is the (A)ATSR QWG which makes technical recommendations on changes to the algorithms and products as a result of the feedback from the underpinning activities. These recommendations are used by the funding partners to determine their funding priorities. The relationship between the various bodies involved is shown in Figure 5-2.

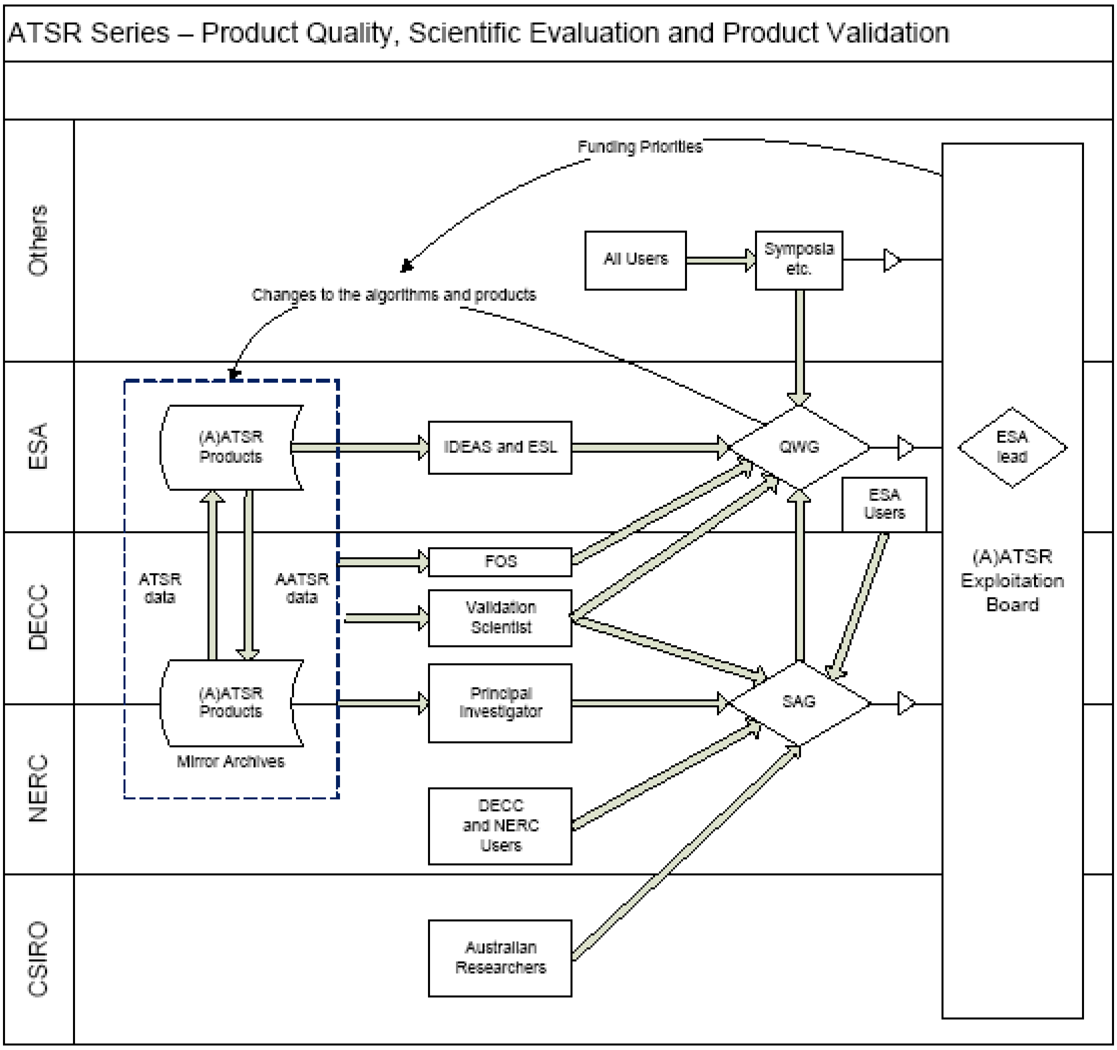

Figure 5-2: (A)ATSR quality and product improvement cycle

Many of the actions described under this section are relevant to long-term data operations and therefore apply not only to the past (A)ATSR instruments but also to the future SLSTR on Sentinel-3. This increases the incentive to improve the current operational products of AATSR but also to increase the portfolio of such products that will be available from the Sentinel-3 instrument. This can be considered to be an excellent investment in resource since long-term data series will be much in demand for GMES and the ESA ECV programmes.

5.8 Recommendations for further work

The AATSR project has made some important steps forward and the following recommendations will significantly enhance the return from the mission:

1. A formal plan, to be issued by the QWG and endorsed by the SAG, for the revision of existing operational products and the roll-out of new AATSR operational products.

2. A formal process for identification of “official” (A)ATSR products, with increased emphasis on consistent processing of all three data records.

3. Support for the development of new algorithms to realise the full potential of (A)ATSR data.

4. Support for verification and validation activities of all (A)ATSR “official” products”, led by the Validation Scientist.

5. The development of AATSR product generation as an example for the CEOS initiative, QA4EO.

6. Continuity of the operational product line of Sentinel-3 with the operational product line for AATSR as agreed in point 1.

7. Further development of processing facilities for large-scale analysis of (A)ATSR data, for example in the ESA Grid Processing On Demand (G-POD) facilities, to be able to analyse data with due regard to IPCC timescales, for example. This ability should extend to the entire (A)ATSR record, from all three instruments.

8. Further development of interfaces to the (A)ATSR data archive, to facilitate easy user exploitation.

6 REFERENCE DOCUMENTS

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APPENDIX A: LIST OF ACRONYMS

AATSR	Advanced Along-Track Scanning Radiometer
(A)ATSR	All three ATSR instruments
AEB	(A)ATSR Exploitation Board
AEP	(A)ATSR Exploitation Plan
AO	Announcement of Opportunity
AOD	Aerosol Optical Depth
(A)RC	(A)ATSR Re-analysis for Climate
ATSR	Along-Track Scanning Radiometer
ATSR-1	The ATSR instrument on the ERS-1 satellite
ATSR-2	The ATSR instrument on the ERS-2 satellite
CCN	Cloud Condensation Nuclei
DEC	[AATSR] Data Exploitation Contract
Defra	Department for Environment, Food and Rural Affairs
DUE	Data User Element
DUP	Data User Programme
ECMWF	European Centre for Medium Range Weather Forecasting
ECV	Essential Climate Variable
ENSO	El Niño/Southern Oscillation
Envisat	Environmental Satellite
EO	Earth Observation
EOEP	Earth Observation Envelope Programme
ERS	Earth Remote Sensing satellite
ESA	European Space Agency
ESRIN	European Space Research Institute
EU	European Union
*f*APAR	*fraction* of Absorbed Photosynthetically Active Radiation
GCOS	Global Climate Observing System
GHRSST-PP	GODAE High Resolution SST Pilot Project
GMES	Global Monitoring of the Environment and Security
GODAE	Global Ocean Data Assimilation Experiment
G-POD	Grid Processing On Demand
GRAPE	Global Retrieval of ATSR Cloud Parameters and Evaluation

IPCC	Intergovernmental Panel on Climate Change
ITT	Invitation To Tender
L2P	[GHRSST-PP] Level 2 Products
LAI	Leaf Area Index
LRTAP	Long Range Transport Atmospheric Pollutants
LST	Land Surface Temperature
NDVI	Normalised Difference Vegetation Index
NEODC	NERC Earth Observation Data Centre
NERC	Natural Environment Research Council
NRT	Near Real Time
NWP	Numerical Weather Prediction
OSTIA	Operational Sea Surface Temperature and Sea Ice Analysis
PI	Principal Investigator
QA	Quality Assurance
QA4EO	Quality Assurance for Earth Observation
QC	Quality Control
QWG	Quality Working Group
RAL	Rutherford Appleton Laboratory
SAG	Science Advisory Group
SERC	Science and Engineering Research Council
SEP	Science Exploitation Plan
SLSTR	Sea and Land Surface Temperature Radiometer
SSES	Single Sensor Error Statistics
SST	Sea Surface Temperature
ToA	Top of Atmosphere
TBC	To Be Confirmed
TBD	To Be Decided
UV	Ultra Violet
VS	Validation Scientist
WMO	World Meteorological Organisation

APPENDIX B: (A)ATSR PRODUCTS

B.1. ATSR products

ATSR information is extracted from http://www.atsr.rl.ac.uk/dataproducts/index.shtml

B.2.2. UBT - Ungridded Brightness Temperature

UBT is an ungridded brightness temperature/reflectance product (a new product for SADIST-2). The product contains ungridded, calibrated brightness temperatures or reflectances from all or some of the ATSR-1/ATSR-2 detectors. Although the product remains ungridded, it may optionally contain pixel latitude/longitude positions, and/or pixel X/Y (across-track/along-track) co-ordinates.

Ungridded products contain pixels in the ATSR scan geometry. There is a correspondence between the contents of a record and the contents of an ATSR instrument scan.

Archiving note: This product was produced for NERC and later processed into AATSR L1B format for the Defra and ESA (A)ATSR Archive.

B.2.3. GBT - Gridded Brightness Temperature

GBT is a gridded brightness temperature/reflectance product (an extension of the SADIST-1 BT product). The product contains gridded, calibrated brightness temperatures or reflectances from all or some of the ATSR-1/ATSR-2 detectors. The product optionally includes pixel latitude/longitude positions, X/Y offsets (sub-pixel across-track/along-track) co-ordinates.

Gridded products contain 512 x 512 pixel images. The correspondence between pixel and the ATSR instrument scan from which it came has been lost. Nadir and forward view pixels are collocated, and have been regridded onto a 1km grid.

B.2.4. GSST - Gridded Sea Surface Temperature

GSST is a gridded sea-surface temperature product (an extension of the SADIST-1 SST product). The product contains gridded sea-surface temperature images using both nadir-only and dual view retrieval algorithms. The product optionally includes pixel latitude/longitude positions, X/Y offsets (sub-pixel across-track/along-track) co-ordinates, and the results of cloud-clearing/land flagging.

Gridded products contain 512 x 512 pixel images. The correspondence between pixel and the ATSR instrument scan from which it came has been lost. Nadir and forward view pixels are collocated, and have been regridded onto a 1km grid.

B.2.5. ASST - Average Sea Surface Temperature

The ASST product contains 10 arcminute spatially-averaged SSTs, grouped into 0.5 degree cells, with associated positional and confidence information, derived from up to a complete file of ATSR raw data (which may in most circumstances be considered to be equivalent to one ERS orbit).

B.2.6. Average Brightness Temperature

ABT is a spatially-averaged brightness temperature /reflectance product. The product contains spatially-averaged brightness temperature /reflectance from some or all of the ATSR-1/ATSR-2 detectors, categorised by view, channel, surface type and cloud presence.

Definition: Consolidated products are time ordered with no overlaps or data gaps (except when the instrument is not operating). They are produced offline.

B.2.7. GBROWSE low resolution product

GBROWSE is a gridded browse product (an extension of the SADIST-1 BROWSE product). The product contains gridded sub-sampled, calibrated brightness temperature or reflectance images from some or all of the ATSR-1/ATSR-2 detectors. The product optionally includes the results of cloud-clearing/land flagging.

B.2. ATSR processing history

B.2.1. SADIST-2 version history

v100: First release of SADIST-2. ATSR-2 data only processed. Uses the same cloud-clearing as SADIST-1 but incorporates new product formats with greatly improved header information and a totally new Level 1 processing scheme.

v200: Improved cloud-clearing scheme adopted, incorporating new versions of the 1.6 µm Histogram Test and the Infrared Histogram Test.

v201: Corrects bug in the 1.6 µm Histogram Test to correctly set the sun-glint flag. (Previously was always flagged with “no sun-glint”.)

v203: Corrects a bug in the function “CloudQuantityTest” within the 1.6 µm Histogram Test (previously caused an occasional crash, so products are not affected).

v213: New format ABT product introduced giving higher precision in brightness temperature data.

v300: Introduces ATSR-1 as well as ATSR-2 processing capability. There are no differences with respect to v213 as far as ATSR-2 processing is concerned. ATSR-1 data are now available (for the first time) with the improved cloud-clearing scheme and better Level 1 processing.

v301: Cloud-clearing improved - new 11 µm Spatial Coherence Test introduced. Level 1 processing modified to exclude data affected by extreme cases of scan-mirror "jitter".

v302: Corrects a bug in the 11 µm Spatial Coherence Test (previously caused an occasional crash, so products are not affected).

v303: Corrects a bug in the Infrared Histogram Test which occasionally gave conflicting forward-view with respect to nadir-view cloud-flagging.

v310: Improved SST-retrieval algorithm and coefficients introduced.

v320: Y2K compliant version. (This version is functionally identical to v310.)

v321: Allows calibration of reflectance channels when ATSR-2 is in the non-nominal fixed gain and offset mode of operation. In addition, the ABT product content is amended to include the forward-view-only data at the end of each Level 0 input file.

v322: Uses new improved SST-retrieval tables (for ATSR-2 only).

v330: Incorporates ATSR-1 FPA-temperature-dependent SST retrieval coefficients updated (in their derivation) to match those introduced for ATSR-2 at v322.

v340: Cloud-clearing scheme harmonised with that used for AATSR

v350: Extends header information in UBT headers to support metadata in NEODC Archive

v356: Corrects bug in ATSR-1 1.6 µm calibration.

Note with respect to numbering sequence: Only the above version numbers were used operationally.

Note with respect to (A)ATSR Archive: Only v350 and v356 were used to generate UBTs for the (A)ATSR archive.

B.2.2. SADIST versions – SST coefficients used

v100 to v303 coefficients

Original coefficients based on a scheme having 10 across-track bands.

v310 to v321 coefficients

Revised scheme for ATSR processing uses new treatment of stratospheric aerosol (C.J. Merchant et al 1999). Aerosol robust coefficients were developed by Merchant et al. (This was done in order to generate coefficients insensitive to the presence of stratospheric aerosol.)

New across-track banding scheme. Earlier versions used a scheme of 10 bands across the swath with five bands from centre to edge (Zavody et al 1995). The new scheme with 76 bands was incorporated to reduce discontinuities at band edges. (Thirty-eight bands from centre to edge.)

v322 onwards coefficients

Corrects known errors in derivation of ATSR-2 coefficients used in v310 to v321. Not introduced until v330 for ATSR-1.

N.B. For more detailed information on coefficients retrieval see “Generation of Retrieval Coefficient Sets for ATSR-1/2” (presentation to ATSR Core Group, 11-Oct-2001).

B.2.3. ATSR reprocessing status

Archive V2 (current version) for ATSR-1 and ATSR-2

Processor versions used:

L1b Processor:

STEP 1.3	used for all of the ATSR-1 data and most of the ATSR-2 data except:
STEP 1.4	ATSR-2 data acquired during the post-gyro-failure, pre-ZGM-YSM era

L2 Processor:

Proto2-L/0.5	Used for data acquired throughout both missions

Completeness

ATSR-1 data:

All available input orbits between August 1991 through until the nominal end-of-mission in early June 1996 (plus occasional, brief restarts thereafter).

ATSR-2 data:

All available input orbits between June 1995 and June 2003 (end of onboard tape-recorder life).

Data coverage is summarised on the Archive website at:

http://www.neodc.rl.ac.uk/docs/atsr/atsr2_coverage.pdf (for ATSR-2)

http://www.neodc.rl.ac.uk/docs/atsr/atsr1_coverage.pdf (for ATSR-1)

Archive V1 for ATSR-1 and ATSR-2

Processor versions used:

L1b Processor:

STEP 0.0+	Used for all ATSR-1 data & ATSR-2 data acquired under ERS-gyro control (up to January 2001)
STEP 0.7+	Used for ATSR-2 data acquired in the ERS-2 ZGM-YSM-era

L2 Processor:

Proto2	Used for data acquired throughout both missions

Completeness

As above but with the exception that the L1b processor of that era had only an experimental version of the current ATSR-2 attitude-correction software. Consequently, no data between January 2001 and December 2002 were processed.

(A)ATSR Product Quality Evolution Summary for ATSR-1 and ATSR-2

For both ATSR-1 and ATSR-2, their Envisat-style products are based on “UBT” input from SADIST-2, v350 or v356. These SADIST-2 versions are functionally identical to each other as far as UBT products are concerned. UBTs have already been through L0-to-L1 processing (by SADIST-2). The subsequent transformation to Envisat style products is done in two stages:

1. From framed, calibrated but ungridded L1 products (UBT) to gridded, geolocated and calibrated L1B products via the **STEP** processor.
2. From L1B to L2 via the **Proto2-L** processor

The following product content improvements were made between V1 and V2 of the Archive:

L1B (Envisat “TOA”) Products:

1. Corrected errors in the forward-view solar angles (previous errors affected only the first two frames of each product).
2. Corrected the stated number of DSDs in the MPH.
3. Corrected the forward-view blanking pulse flags in the corresponding MDS.
4. Harmonised the cloud-flagging scheme with that of the AATSR IPF.
5. Attitude-correction software introduced to improve ATSR-2 geolocation for the ERS-2 post-gyro-failure era.

L2 (Envisat “NR” and “AR” products)

Note that improvement 1 above automatically corrected the same error previously found in L2 gridded (NR) products.

1. Corrected the AR product confidence word with respect to 3.7μm channel usage and harmonised confidence word structure with that used in the AATSR IPF.
2. Corrected invalid land-surface temperature (LST) values in the AR product.

3. Corrected errors in the AR product 30 arc-minute sea-surface temperature (SST) MDS. These errors previously affected the following SST-related fields: standard-deviation, cloud-top temperature (forward-view) and percentage cloud-cover (forward-view).

4. Corrected the (previously unfilled) “referencing DSD” for the LST auxiliary data. This correction was required to the SPH of both the gridded (NR) and the averaged (AR) L2 products.

5. Introduced the attitude correction flag in the PROC_CENTER field of the METEO product MPH. Previously this flag was omitted.

Final important note with respect to ATSR-2 data in the archive as of May 2009

It was discovered recently that there is a systematic data omission ***within*** certain L1b products which in turn affects the corresponding L2 products. ***Within*** means that the affected orbit products exist in the archive but that a significant fraction of the acquired data from the orbit is missing. This omission has been tracked to input UBTs being rejected owing to “null” attitude-flags in their headers. There is a work-around in place which will effectively “fill” the affected orbits.

When present, this problem usually affected two orbits per day. The correction process will provide statistics on exactly how many orbits were affected and during which periods of the mission.

B.3 AATSR products

AATSR product information is extracted from the AATSR Flight Operations and Data Plan (FODP) and the Envisat website at
http://envisat.esa.int/instruments/aatsr/data-app/dataprod.html

B.3.1. AATSR product summary table

AATSR	Processing Level	Product ID Size Mbytes / COVERAGE
Level 0	AATSR 'Raw Data'	ATS_NL__0P 490 Mbytes / orbit
Level 1b	TOA Radiance (localisation, calibration, angles appended) in the 7 channels, both nadir and forwards views.	ATS_TOA_1P 8.4Mb / 512km*512km 656 Mbytes / orbit
Level 2	Sea, Land and Clouds geophysical parameters	ATS_NR__2P 1.6 Mb / 512km*512km 123 Mb / orbit
Level 2	Spatially Averaged Product (10 x 10 arcminutes per cell)	ATS_MET_2P 4.5 Mbytes/orbit
Level 2	Spatially Averaged Product (50 x 50 km and 30 x 30 arcminutes per cell and 17 km x 17 km and 10 x 10 arcminutes per cell)	ATS_AR__2P 0.5Mbytes/orbit
Level 2P	Full resolution SST product, in GHRSTT format	ATS_NR_L2P
Browse	Compressed, three colour composite derived from nadir-only view at 4 km resolution, to support user searches	

Archiving notes:

The archive comprises ATSR-1, ATSR-2 and AATSR consolidated datasets in AATSR format.

The L1b dataset should not change in the future as it is an engineering product derived from the instrument characteristics.

The L2 products will change as more knowledge of the atmospheric effects that influence the generation of SSTs and LSTs is gained.

GHRSST-PP L2P products will be added to the list of approved products in 2008.

MPH = Main Product Header, the description record at the start of every product (generic format).

SPH = Secondary Product Header

MDS = Measurement Data Set, a defined data entity within a product.

ADS = Annotation Data Set

B.3.2. AATSR product tables

PRODUCT ID	**ATS_TOA_1P**
NAME	TOAR at full resolution for all channels and both views
DESCRIPTION	AATSR products calibrated and geolocated and FV and NV collocated
COVERAGE	512 km x 40 000 km
THROUGHPUT	1 product per orbit every 100'
GEOMETRIC RESOLUTION	Resampled 1 km x 1km along track
MAXIMUM SIZE	512 x 32 bytes x 40 000 = 656 Mbytes (7 bands in nadir and forward view = 14 bands + Annotation Information equivalent to 2 bands)
RADIOMETRIC RESOLUTION	Coded on 16 bits,
RADIOMETRIC ACCURACY	for VIS/NIR channel 5% relative to the sun for IR channels < 0.1 Kelvin
DATASET	MPH SPH MDS ADS
AUXILIARY DATA	MPH Orbit state vector, Time correlation parameters, Instrument characterization files. Pressure, Water Vapour, Wind speed, Temperature
NOTES	Produced systematically, On demand dissemination of multiple of scene size 512km x 512km or full orbit

PRODUCT ID	**ATS_NR__2P**
NAME	geophysical product
DESCRIPTION	AATSR geophysical product for ocean and land Scene Floating Concept for dissemination
COVERAGE	512 km x 40 000 km (multiple of scene can be ordered)
THROUGHPUT	1 product per orbit every 100'
GEOMETRIC RESOLUTION	Resampled 1 km x 1km along track
MAXIMUM SIZE	512 x 6 bytes x 40 000 = 123 Mbytes
RADIOMETRIC RESOLUTION	Coded on 16 bits for the SST, dependent on gain and channel
RADIOMETRIC ACCURACY	for VIS/NIR channel 5% relative to the sun for IR channels < 0.1 Kelvin
DATASET	MPH SPH MDS ADS
AUXILIARY DATA	Surface identification flags included in the level 1b product Auxiliary data (see previous spreadsheet)
NOTES	Produced systematically On demand dissemination of multiple of scene size 512km x 512km or full orbit

PRODUCT ID	**ATS_MET_2P**
NAME	AATSR level 2 spatially averaged
DESCRIPTION	Climatology product Average Sea Surface Temperature With confidence information on a cell basis
COVERAGE	512 x 40000 km
THROUGHPUT	1 orbit per 100 '
GEOMETRIC RESOLUTION	10 x 10 arcminutes per cell
SIZE	About 5 Mbytes/orbit
RADIOMETRIC RESOLUTION	0.01 degrees for SST
RADIOMETRIC ACCURACY	0. 5 degrees Kelvin for SST
DATASET	MPH SPH MDS ADS
AUXILIARY DATA	Surface identification flags Auxiliary data as previous spreadsheet
NOTES	Produced systematically, dissemination on an orbit basis

PRODUCT ID	**ATS_AR__2P**
NAME	AATSR level 2 spatially averaged
DESCRIPTION	Climatology product AATSR Spatially Averaged Sea/Land Geophysical product - Average Sea Surface Temperature With confidence information on a cell basis
COVERAGE	512 x 40000 km
THROUGHPUT	1 orbit per 100 '
GEOMETRIC RESOLUTION	50 x 50 km and 30 x 30 arcminutes per cell and 17 km x 17 km and 10 x 10 arcminutes per cell
SIZE	About 63 Mbytes/orbit
RADIOMETRIC RESOLUTION	0.01 degrees for SST
RADIOMETRIC ACCURACY	0. 5 degrees Kelvin for SST
DATASET	MPH SPH MDS ADS
AUXILIARY DATA	Surface identification flags Auxiliary data see previous spreadsheets
NOTES	Produced systematically

B.4. AATSR processing history

The following information is from IDEAS-VEG-OQC-REP-0225, dated 12 January 2009.

February 2002 – IPF V5.01

Launch version.

June 2002 – IPF V5.02

Scan jitter error corrected. The IPF wrongly treated scans affected by scan mirror jitter as invalid, resulting in missing scans on images.

Browse algorithm modified to provide visual improvements. Histogram equalisation was removed from the daytime algorithm and the night-time algorithm concept was simplified.

July 2002 – IPF V5.52

Internal change (i.e. not affecting the processing algorithms) to address an overflow problem with the variable SAT_BINARY_TIME.

September 2002 – auxiliary data update: ATS_VC1_AX

New ATS_VC1_AX (Visible Channel Coefficients Data) file supplied to correct scaling errors in pre-launch file (shortly after, replaced by daily VC1 files provided by the AATSR Flight Operations Support team).

October 2002 – auxiliary data update: ATS_INS_AX

New ATS_INS_AX (Instrument Data) file supplied to prevent spurious BBU temperature validation warnings (internal issue, not visible in delivered data).

14 November 2002 – auxiliary data update: ATS_CH1_AX

New ATS_CH1_AX (L1B Characterisation Data) file submitted to the PDS containing updated misalignment parameters, AOCS parameters and regridding tolerances. This improved the co-location between the forward and nadir views.

January 2003 – IPF V5.55

Update containing modifications to the VISCAL algorithm, and associated ATS_PC1_AX (L1B Processing Configuration Data) auxiliary file. The original VISCAL algorithm did not work with real AATSR data because of undocumented differences in VISCAL monitor sampling between

ATSR-2 (from which all test data were derived) and AATSR. The VISCAL GADS in all L1B data generated prior to this date were missing.

March 2004 – IPF V5.58

Update containing:

- A new L2 LST retrieval algorithm (only applied within the ATS_NR__2P product, not available in ATS_AR__2P);
- A further modification to the VISCAL search algorithm to allow it to search backwards from the time of the OSV in the MPH (required for NRT data which is not partitioned from ANX to ANX and where the VISCAL peak may precede the OSV).

July 2004 – IPF V5.59

Update containing:

- A change to the facility responsible for setting the REF_DOC field in the MPH (from PFHS to IPF);
- A change to the internal handling of CFI warning messages.

Neither of these changes have any impact on the delivered data.

August 2004 – auxiliary data update: ATS_PC1_AX

New ATS_PC1_AX (L1B Processing Configuration Data) file supplied, updated with revised solar irradiance data (carried through into the output VISCAL GADS in the L1B product).

14 December 2004 – auxiliary data update: ATS_GC1_AX

New ATS_GC1_AX (General Calibration Data) file supplied, to correct the application of the 1.6 micron non-linearity correction.

29 November 2005 – auxiliary data update: ATS_VC1_AX

Daily ATS_VC1_AX files were modified to account for long-term visible channel drift.

07 December 2005 – auxiliary data update: ATS_SST_AX

Revised SST retrieval coefficients were introduced in ATS_SST_AX (SST Retrieval Coefficients Data).

- ATS_SST_AXVIEC20051205_102103_20020101_000000_20200101_000000

The retrieval coefficients previously in use were based on the same atmospheric spectroscopy as was originally used for ATSR-1 and ATSR-2, which pre-dated more recent releases of the HITRAN molecular spectroscopy database. The new set of retrieval coefficients were based on the HITRAN 2000 database.

15 June 2006 – change of configuration parameter

The cell sizes in the AST product were previously fixed to 16/48 km, disregarding the contents of the ATS_PC2_AX (L2 Processing Configuration Data) file. This anomaly was corrected so the cell sizes are 17 and 51 km from 15 June 2006 onwards.

18 December 2006 – auxiliary data update: ATS_VC1_AX

ATS_VC1_AX files were modified to include the updated behaviour model of the visible channel long-term drift.

18 January 2007 – IPF V5.60

The patch was to correct for two previously identified problems in the software: inconsistent values in AST confidence word and cloud flagging errors leading to bands of missing data in AATSR consolidated data. Further information is contained in the AATSR Cyclic Report 54, which is available from http://earth.esa.int/pcs/envisat/aatsr/reports/cyclic/.

01 February 2007 – auxiliary data update: ATS_VC1_AX

Delivery of orbital ATS_VC1_AX files commenced, alongside delivery of daily files.

28 March 2007 – IPF V6.0

IPF 6.0 includes improvements to the LST algorithm and cloud clearing tests. These changes affect both the Level 1 and Level 2 processing. In summary the specific improvements are:

- The improvement of the performance of the cloud clearing tests over land;
- An improved treatment of pixels in areas of marginal cloud;
- To enable the LST retrieval over inland lakes;
- To implement and test the spatially averaged LST retrieval.

To support the updated cloud regimes, a new ATS_CL1_AX (Cloud Lookup Table Data) file was delivered.

02 July 2007 – IPF V6.01

The patch for IPF 6.01 corrects for an erroneous calculation of the ANX during consolidated processing, leading to missing Viscal GADS in the L1B products.

20 July 2007 – auxiliary data update: CH1, GC1, INS, LST, PC1

The validity range of several auxiliary files was updated to provide continued coverage in line with the validity range of other auxiliary files. The content of these files was unaffected. An up to date list of auxiliary files in use is included in the AATSR Cyclic Reports (http://earth.esa.int/pcs/envisat/aatsr/reports/cyclic/).

Note: this is the nominal configuration used for the Second Reprocessing of AATSR data.

B.5. (A)ATSR data availability

ESA Users

ESA Cat1 users access the archive at ESA's UK-MM-PAF facility. The process to request access is defined on Earthnet Online. Successful applicants will be issued with logon credentials to access the data. Data products are available through ftp or MERCI (web interface). All products are available via ftp for all three ATSR missions: L1b, L2 NR, L2 AR and L2P NRT products. L2P archive products will be available for all three ATSR missions in July 2009. L1b and L2 NR products are also available via MERCI for AATSR and ATSR-2. ATSR-1 products are currently being registered. This activity will be completed by October 2009. Note that L2 AR and L2P products are not available via MERCI. The MERCI webpage at UK-MM-PAF has up to date information for data availability.

NEODC Users

UK users with bona fide academic research or educational needs should register with the NEODC and may then apply for access to the (A)ATSR dataset. successful applicants will be issued with logon credentials to access the data. Data products are available through ftp or via the NEODC web interface. All products are available via ftp for all three ATSR missions: L1b, L2 NR, L2 AR and L2P NRT products. L2P archive products will be available for all three ATSR missions in June 2009. the NEODC/(A)ATSR webpage at:

http://www.neodc.rl.ac.uk/?option=displaypage&itemid=91&op=page&submenu=91

has up to date information on data availability.

APPENDIX C: ESSENTIAL CLIMATE VARIABLES

The Global Climate Observing System (GCOS) recognises 44 Essential Climate Variables (ECVs) that are both feasible for global implementation and have a high impact on UNFCCC requirements – see Table 1 (reproduced from RD003, Table 1). Several emerging ECVs have also been proposed.

RD002 defines the subset of ECVs that can be addressed by spaceborne instruments, and Tables 2 to 4 below discuss the sub-subset of ECVs that can be addressed by (A)ATSR. These ECVs are identified in Table 1 with an asterisk. For each ECV listed below, a reference is provided to a section in RD002.

Table 1: Essential Climate Variables (ECVs) that are both feasible for global implementation and have a high impact on UNFCCC requirements

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour (*).
	Upper air: Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties (*)
	Composition: Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases, Aerosol properties (*)
Oceanic	**Surface:** Sea-surface temperature (*), Sea-surface salinity, Sea level, Sea state, Sea ice (*), Current, Ocean colour (for biological activity), Carbon dioxide partial pressure.
	Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton
Terrestrial	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type) (*), Fraction of absorbed photosynthetically active radiation (FAPAR) (*), Leaf area index (LAI) (*), Biomass, Fire disturbance (*)

Table 2: Atmospheric ECVs

ECV	Comment
Upper-air Water Vapour Profile (ECV Product A.3.2 - see RD002 3.1.3)	(A)ATSR data have been used to deduce water vapour content of the atmosphere on a global basis. This is possible because the atmospheric correction process intrinsically estimates water vapour absorption and emission. The feasibility of generating water vapour fields has been demonstrated but the technique has not yet been subjected to rigorous evaluation or been compared with other techniques. However, it must be remembered that (A)ATSR channels are not well suited to detection of other atmospheric constituents, in fact they are chosen to avoid or minimise atmospheric absorption.
Cloud Properties (ECV Product A.4 - see RD002 3.1.4)	Strong potential for (A)ATSR Products (see Section 3.5)
Aerosol Properties (ECV Product A.8 - see RD002 3.1.8)	Strong potential for (A)ATSR Products (see Section 3.5)

Table 3: Oceanic ECVs

ECV	Comment
Sea Surface Temperature (SST) (ECV Product O.3 - see RD002 3.2.3)	Main part of existing (A)ATSR dataset
Sea Ice (ECV Product O.1 - see RD002 3.2.1)	Proposals for developing an (A)ATSR Sea-Ice product have been made. It is an increasingly important area for climate change and more priority is needed in this area (see Section 3.6)

Table 4: Terrestrial ECVs (including Emerging ECVs)

ECV	Comment
Fire Disturbance (ECV Product T.9 - see RD002 3.3.9)	(A)ATSR data are the main input to the ESA Fire Atlas
Land Cover (ECV Product T.5.1, T.5.2 - see RD002 3.3.5)	(A)ATSR data can contribute to a “medium” resolution land cover ECV by providing verification both from thermal/LST data and also from surface reflectance data. (A)ATSR surface reflectance data should be very accurate because the dual-view offers improved atmospheric correction.
Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) (ECV Product T.6 - see RD002 3.3.6)	
Leaf Area Index (LAI) (ECV Product T.7 - see RD002 3.3.7)	
Land Surface Temperature (LST) (Emerging ECV – Supporting Product to T.5.1 and T.5.2)	Part of existing (A)ATSR dataset but currently being validated
Lake Surface Temperature (Emerging ECV – see RD002 3.3.1)	An ESA research project is currently investigating the feasibility of a lake surface temperature product.

APPENDIX D: COMPLETED PROJECTS

D.1 Purpose of this appendix

Appendix C contains information on the (A)ATSR activities already completed by the funding agencies, to be used as a reference to the work that has been done so far.

The appendix summarises each funding agency's contracts in addition to brief notes about the completed work. In some cases, similar contracts for ongoing work have been issued and these listed in Appendix D as ongoing projects.

All the numbers in this appendix are available to the public via various websites and publications

D.2 The Australian contribution

Australia participated in all three ATSR programmes, principally to develop Australian industrial capabilities and to support SST validation.

The Australian-funded work is summarised in the table below:

Activity	Start	End	Price /AUS$
ATSR-1 Components	TBC	TBC	TBC
ATSR-1 industrial activities.			
ATSR-2 Components	TBC	TBC	TBC
ATSR-2 industrial activities, including FPA and Fore Optics.			
AATSR Components	1991 TBC	1998 TBC	TBC
AATSR industrial activities, including FPA and Fore Optics.			
(A)TSR Science and Validation	1991 TBC	1998 TBC	TBC
(A)ATSR science and validation activities (CSIRO)			
		Total Investment	AUS$ TBC

D.3 The BNSC contribution

BNSC has funded a study into SST data continuity, to examine how to accommodate a possible break in flight operations between AATSR and SLSTR, as part of its International Co-operation Programme (ICP2).

Activity	Start	End	Price /£K
AATSR Science and Validation	12 2006	11 2007	33
ICP2 project: SST data continuity. Price includes a contribution of £5,756 from Space ConneXions, the University of Leicester and NOCS. The final report is available on http://www.icp2.net/			
		Total Investment	£K 33

D.4 The DECC AATSR programme

DECC's (formerly DoE, DETR and Defra) programme was initiated in 1992 when the then Department of the Environment funded a Phase B contract with RAL to define the requirements for the AATSR instrument. This was followed in 1993 by a Management Information System (MIS) contract awarded to VEGA Group plc to initiate a procurement process to build the instrument and its associated ground segment. The contract to build the instrument was awarded to British Aerospace (now part of Astrium) and a contract was awarded to RAL to build the AATSR prototype processor. The Principal Investigator and Validation Scientist roles were contracted to the University of Leicester.

Following the launch of Envisat, Defra continued to fund AATSR flight operations support, AATSR prototype processor maintenance, and PI and VS activities, all co-ordinated under VEGA's MIS contract. In 2003, Defra consolidated all their contracts bar the Astium contract under a Data Exploitation Contract (DEC), which was awarded to Space ConneXions Limited. This contract covered the previously mentioned activities plus the (A)ATSR archive development at RAL and the ISAR validation contract with the National Oceanography Centre, Southampton (NOCS).

In addition to the work related directly to AATSR, DECC funds the Met Office Hadley Centre programme which is the main customer for the (A)ATSR SST dataset. MOHC uses these data in their analyses of climate change.

The DoE, DETR and Defra-funded work is summarised in the table below:

Activity	Start	End	Price /£M
AATSR Instrument & Flight Operations Support	1992	2008	13.6
AATSR Phase B. Definition of a complete set of AATSR specifications for use in the procurement process by DoE and the Australian Space Office (ASO). AATSR instrument prime contract. AATSR flight operations support.			.
AATSR Management Information System	04 1993	06 2004	1.7
Technical and management support to DoE on AATSR matters, including coordination and management of AATSR instrument procurement and the procurement of the associated ground segment.			
AATSR Science and Validation	1995	2008	1.9
AATSR Principal Investigator contract, including coordination and management of AATSR SAG activities and early Validation Scientist tasks.			
(A)ATSR Prototype Processors and Archive	1995	2008	2.3
AATSR prototype processor development and maintenance.			
		Total Investment	£M 19.5

More information can be found by entering "AATSR" as a keyword in the search box on http://randd.defra.gov.uk/Default.aspx?Location=None&Module=FilterSearchNewLook&Completed=0

D.5 The ESA contributions to the (A)ATSR programme

ESA has funded industry to support the integration of the ATSRs on ERS-1, ERS-2 and Envisat, and to develop the ESA part of the (A)ATSR ground segment. In addition, ESA has funded several validation contracts.

The ESA-funded work is summarised in the table below:

Activity	Start	End	Price /M€
(A)ATSR flight operations	1991	2008	2.7
ATSR-1, ATSR-2 and AATSR flight operations at ESOC.			
(A)ATSR quality and product improvement	1991	2008	3.2
Includes ground segment activities coordinated via the QWG			
AATSR validation	~2003	2008	0.5
Includes SISTeR and LST validation activities.			
(A)ATSR data exploitation	TBC	2008	2.4
GlobCarbon: 1.2 Meuro (with Vegetation also) Medspiration: 1.2 Meuro (with all other SST sensors)			
		Total Investment	M€ 8.8

D.6 The ESA Data User initiatives

D.6.1 Objectives of the Data User initiatives

ESA's Data User initiatives are the Data User Element (DUE) and its Data User Programme (DUP) predecessor. Both programmes were set up to encourage the establishment of a long-term relationship between user communities and providers of Earth Observation data and information.

The three major objectives of DUE, as stated in the Programme Declaration, are:

1. To create an environment allowing for the development of user communities for both institutional and commercial applications
2. To support European companies in the development and demonstration of information products derived from current and future ESA missions
3. To support industry - i.e. value adding and service companies - in establishing useful and cost effective services

A number of rules have been established in order to fulfil these objectives. In particular, any DUE project must:

- Respond to clear end-user needs
- Commit *identified* end-users as active partners of the project
- Build on already established research results
- Develop information products using EO data as one of the inputs
- Demonstrate service provision as a real operational test case for the user
- Lead to a sustainable service in the short term
- Be innovative

Thus the DUE programme is intended to stimulate the development of operational systems to meet the needs of end-users.

D.6.2 User participation

The DUE has the user as its top priority. The direct and active involvement of user organisations is mandatory in all DUE projects. This involvement is aimed primarily at developing EO-based products and services responding to real user needs. The definition, implementation, integration, validation and qualification of these products and services are carried out in close collaboration with these end-user organisations, and in agreement with their standards and practices.

The overall DUE procurement approach aims at fostering an effective collaboration with these user communities. Part of the programme is dedicated to discovering potential users and then educating them about the capabilities of EO within their own working framework. This is termed the *User Breeding Path* and deals mostly with public sector entities, e.g. national ministries, non-governmental organisations, international scientific programmes and international conventions.

The notion of *Champion Users* is central to DUE and implies that user organisations under consideration for participation for a DUE demonstration project should possess the following attributes:

- Some representation and influence;
- Some dissemination capability;
- Some technical capability and data access;
- Some funding capacity and prospects for future development;
- The will to explore the potential of EO technology as well as to incorporate EO technology within their internal working procedures.

The involvement of a *Champion User* at programme level is essential. The aim should be to gather the information needed by the user community before issuing an ITT in order to focus on key topics of interest for the overall user community and to better respond to specific user needs and requirements.

Having a *Champion User* at project level is also critical. This is to ensure that the final products and services derived from DUE projects respond to the specific needs of the corresponding user communities as well as allowing users to have direct contact with the products and/or services developed, so that they can appreciate the benefits and advantages of EO technology.

In order to be eligible to participate in DUE demonstration projects, these *Champion Users* are requested to commit the provision of resources in support to the project execution (e.g. manpower, technical expertise, access to data and infrastructure, support to product qualification and service quality assessment). In particular, prior to the elaboration of a DUE procurement, the user organisations are required to confirm and commit the following:

1. To agree to participate in the project and to commit an active contribution to the project execution

2. To federate the involvement of local partners and to identify the operational users who will contribute to the project execution, and in particular to the user requirements consolidation, to the product validation and qualification, and to the service assessment

3. To define the in-kind resources that will be provided in support of the project execution, including manpower and access to data

4. To compile their project requirements in a User Requirement Document (URD) that will be included in an ESA Invitation to Tender (ITT) and constitute the basis of the technical requirements that must be fulfilled by the Contractors. Besides the specific requirements for products and services, the user organisations are also requested to identify the Areas of Interest (AOI) where the products are to be demonstrated and to list the local operational users who will collaborate with the project execution within these areas

5. To promote the results of the projects in their community and in particular within the local organisations that fall under their responsibility

When required by one party, the user participation in DUE projects can be made official in a Project Teaming Agreement to be signed by respective high representatives of the European Space Agency and the subject *Champion User(s)*.

D.6.3 Programme history

The DUP ran in two phases for a total of eight years, with DUP-1 running from 1996 to 2000 and DUP-2 running from 2001 to 2003. The DUP was initially subscribed to by Belgium and the Netherlands in 1996, followed by Switzerland in early 1997. Italy joined in late 1999. Under the DUP, a total of 49 projects with a combined budget of 15 M€ were awarded to companies from the four participating countries.

The DUE programme is integrated in the second period of the Earth Observation Envelope Programme (EOEP), an optional programme of ESA that is currently subscribed to by 14 Member States (Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom). The initial period of DUE covered the time frame 2003 to 2007.

The DUE programme is run by the Project Section of the Exploitation and Services Division within ESA's Earth Observation Science and Applications Department.

The total budget for development within the DUE is circa 15 M€.

D.6.4 DUE projects involving (A)ATSR data

From the projects listed on the ESA DUE website (http://dup.esrin.esa.it/index.asp), eight indicate the use of data from the ATSR series. Of these, the projects that have been completed are:

GlobSCAR – completed in 2002

The aim of this project was to demonstrate a processing chain from the production of monthly global maps of newly burnt surfaces. This project uses only ATSR-2 brightness temperature data at 1 km resolution. The project algorithms and processing chain have recently been applied to ATSR-1, ATSR-2 and current AATSR data to give a long-term record of global burnt area.

GlobCarbon – completed in 2003

The aim of this project was to produce demonstration global Level 3 land products for input to carbon assimilation models. The project looked at aspects of burning, *f*APAR (*f*raction of Absorbed Photosynthetically Active Radiation) and LAI (Leaf Area Index) and also the vegetation growth cycle. ATSR-2 and AATSR visible and thermal measurement data was used to provide data on vegetation coverage and burnt area size.

GLASNOWMAP – completed in 2003

The aim of this project was to define and implement a real time data service for monitoring snow cover changes and glaciers in Alpine regions. AATSR 1km visible data were used to monitor snow cover accumulation over time.

MEDSPIRATION – completed in 2008

This project has produced a new generation of global NRT SST data. The project has developed a new format, Level 2P, which is especially tailored to the needs of operational users. The L2P format is based on NetCDF and has the capability to include both satellite and some relevant *in situ* data. Medspiration constitutes the European element of the international GODAE High Resolution SST Pilot Project (GHRSST-PP), which has led to the parallel generation of several SST data-streams in L2P format, from several satellite and *in situ* sources. Both Medspiration and GHRSST have been highly successful projects and have led to operational exploitation of AATSR. This has arguably been the most significant development in the exploitation of AATSR data to date.

Detailed summaries of the completed DUE projects can be found on the DUE website.

D.7 The NERC ATSR-1 and ATSR-2 programmes

NERC assumed responsibility for the ATSR-1 programme from the former Science and Engineering Research Council (SERC) and funded the ATSR-2 programme.

In addition, NERC has funded studies into the development of new (A)ATSR data products.

The NERC-funded work is summarised in the table below:

Activity	Start	End	Price /£M
ATSR-1 Instrument & Flight Operations Support	1993	2005	10.0
ATSR-1 instrument and ground segment procurement, and flight operations support.			
ATSR-2 Instrument & Flight Operations Support	1993	2005	10.0
ATSR-2 instrument and ground segment procurement, and flight operations support.			
(A)ATSR Scientific Research	~1991	2008	1.3
Includes work on land surface, atmospheric correction, oceanic processes, clouds and aerosols.			
		Total Investment	£M 21.3

APPENDIX E: ONGOING PROJECTS

E.1 Purpose of this appendix

Appendix D contains information on the (A)ATSR programmes that were ongoing at the start of this contract.

E.2 The DECC AATSR programme

DECC continues to fund AATSR flight operations support, AATSR prototype processor and archive maintenance, PI and VS activities, and SST validation using ISAR, all co-ordinated under Space ConneXions' data exploitation contracts. In addition, DECC maintains a separate contract with Astrium for flight operations support and with the University of Edinburgh for the development of climate-quality SST algorithms.

The DECC-funded work is summarised in the table below.

Activity	Start	End	Price /£M
(A)ATSR Reprocessing for Climate – (A)RC	04 2006	03 2010	0.14
(A)ATSR Re-analysis for Climate, (A)RC, aims to improve the quality of SST data used in climate research. The dataset is intended to become Version 3.0 of the (A)ATSR archive. A joint UK programme with NERC and the MoD, in collaboration with ESA.			
(A)ATSR Science and Validation	03 2008	02 2010	0.83
Continuation of science and validation activities undertaken by the University of Leicester and NOCS.			
(A)ATSR Archive and Flight Operations Support	11 2008	10 2010	0.66
Continuation of flight operations support, AATSR prototype processor and (A)ATSR archive development and maintenance undertaken by RAL.			
		Total Investment	£M 1.63

Note that the DECC funding for the work at the Met Office Hadley Centre, which is the principal user of the (A)ATSR data on behalf of DECC, is not included in the table.

E.3 The ESA (A)ATSR programme

ESA continues to funded industry to support the AATSR flight operations on Envisat, and to further develop the ESA part of the (A)ATSR ground segment. In addition, ESA has funded several validation and data exploitation contracts.

The ESA-funded work is summarised in the table below.

Activity	Start	End	Price /M€
(A)ATSR Flight Operations	2009	TBD	1
ATSR-1, ATSR-2 and AATSR flight operations at ESOC.			
(A)ATSR quality and product improvement	2009	TBD	1
Includes ground segment activities coordinated via the QWG			
AATSR validation	2009	TBD	0.5
Includes SISTeR and LST validation activities.			
(A)ATSR data exploitation	2009	TBD	10.8
ATSR World Fire Atlas: 15 years effort internal, over 1 Meuro GlobAerosol: 1 Meuro (with MERIS and SEVERI) GHRSST office: 800 Keuro (contract with UK Met Office) Urban Heat Island: 1 Meuro (ATSR is one of the few data source) GlobVolcano: 1 Meuro (ATSR is used for hot spot) GlobSnow: 1 Meuro (ATSR is one of the data source) Permafrost: 1 Meuro (ATSR LST L2 to be used as one of the few data source) GlobAlbedo: 1 Meuro (ATSR is one of the data source, with MERIS and VGT) GlobVapour: 1 Meuro (ATSR is one of the data source, with MERIS and SEVERI) GlobTemperature: 1Meuro (ATSR is the main data source) Sand and Dust Storm: 1 Meuro (ATSR is one of the data source)			
Total Investment			M€ 13.3

E.4 Ongoing DUE projects involving (A)ATSR data

From the projects listed on the ESA DUE website (http://dup.esrin.esa.it/index.asp), 8 indicate the use of data from the ATSR series. An overview of the projects that are ongoing is as completed follows:

GlobAerosol

This project will produce daily global aerosol maps for 1995-2005 to provide information to users in climate and meteorological research, trans-boundary pollution (Long Range Transport Atmospheric Pollutants - LRTAP) and local air quality agencies. ATSR-2 and AATSR visible reflectance will be used to provide an indication of aerosol optical depth (AOD).

CONTRAILS

This project will map one year (2004) of contrails over Europe and the North Atlantic. The maps are produced by comparing cirrus cloud coverage and air traffic density maps. AATSR thermal radiances will be used in the detection of cirrus clouds.

TEMIS

This project aims to provide a NRT data service of tropospheric trace gas concentrations for air quality monitoring. The project will provide data on various atmospheric trace species for studying ozone loss and surface UV levels, greenhouse gases and local and regional air pollution. ATSR-2 and AATSR visible reflectances will be used in the production of aerosol properties.

TESEO-Carbon

This project aims to use Earth Observation data to support Environmental treaties, in this case the Kyoto Protocol. The project will use information on global CO2 sources and sinks of forests. ATSR-2 and AATSR visible and thermal measurements data will be used to provide data on vegetation coverage and land cover change over time.

GlobSnow

This project (11/2008- 10/2011): is currently investigating the use of ATSR-2 and AATSR for the generation of weekly and monthly global Snow Extent (SE) maps. At the time of writing (May 2009), the algorithm comparisons were underway with the expectation that a preliminary 1995-onwards time series would be available in about 12 months (i.e. around May 2010).

GlobVapour

The objective of this project, which is due to start in autumn 2009, is to merge ATSR/AATSR with other sensors to generate a daily global water vapour column product starting in 1995.

Detailed summaries of the completed DUE projects can be found on the DUE website.

In addition, ESA offers services such as the ATSR World Fire Atlas (http://dup.esrin.esa.int/ionia/wfa/index.asp). A volcano monitoring service (VoMIR) has also been tested.

E.5 Ongoing NERC (A)ATSR programmes

NERC continues to fund science projects related to the use of (A)ATSR data.

The NERC-funded work, including work funded by the NERC Centre for Earth Observation (NCEO) and the APPRAISE programme, is summarised in the table below:

Activity	Start	End	Price /£M
(A)ATSR Reprocessing for Climate – (A)RC	04 2006	03 2010	.50
(A)ATSR Re-analysis for Climate, (A)RC, aims to improve the quality of SST data used in climate research. The dataset is intended to become Version 3.0 of the (A)ATSR archive. A joint UK programme with DECC and the MoD, in collaboration with ESA.			
(A)ATSR Scientific Research	1991	2008	.08
Includes work on land surface, atmospheric correction, oceanic processes, clouds and aerosols.			
		Total Investment	£M 0.58

APPENDIX F: POTENTIAL PROJECTS

Appendix E contains ideas that have been identified by one or more of the funding partners, or by members of the wider (A)ATSR community, that would be ideal candidates for future projects when circumstances permit.

The following pages present potential projects in tabular form.

Note: this section is work in progress

Project Title	Impact of backward view on SLSTR to continuity of data from (A)ATSR
Application and/or Underpinning Activity	Validation, Algorithms, Data Continuity
Objectives	To determine the consequences of a change from a forward to a backward view on SLSTR for existing (A)ATSR products, including SST, LST, clouds and aerosols
Maturity	Sufficient knowledge of the AATSR dual-view characteristics is available to undertake this stage
Justification	Modifications need to be identified to the data processing algorithms and software for SLSTR that will be needed to ensure the continuity of the (A)ATSR datasets. The impact of the change in view needs to be assessed before the CDR of Sentinel-3, so the work needs to be undertaken Any modifications The work is need
Priority	High – need to identify any potential problems with the changed view
Urgency	High – driven by Sentinel-3 CDR
Project Description	TBD
Project Schedule	TBD
Resources Required	TBD
Budget	TBD
Funding Agency	ESA (TBC)

Project Title	(A)RC Lake Temperature Product
Application and/or Underpinning Activity	Lake temperature ECV
Objectives	To prototype a Lake Temperature product for potential adoption as an official ESA product.
Maturity	Tentative lake products exist but they are immature. They can be improved by exploiting the algorithm development work that is being performed on the (A)RC project.
Justification	This will expand the range of products that (A)ATSR can produce and will contribute to an ECV.
Priority	Medium – research project
Urgency	High – funding and effort is available now
Project Description	The surface temperature of lakes in the Global Terrestrial Network for Lakes (GTN-L) is designated as an ECV, product T.1.3 of the Global Climate Observing System (GCOS). In addition, lake temperature products have been requested by several international users, principally through the GHRSST-PP science team since the producers of SST datasets are in a good position to also provide lake temperature datasets. Two fundamental questions to be addressed by the project are: 1. Lake definition: what is a lake (and not a river or an inland sea)? 2. Algorithms: are the usual SST algorithms able to retrieve the lake temperatures with the requested accuracy or do new algorithms need to be designed? The project will investigate to what extent these questions can be answered using (A)ATSR data, by developing prototype products based on the approach used by the (A)RC project.
Project Schedule	2009 – 2012, with go/no go assessments at the end of each year
Resources Required	3 years of post-doctoral research effort, plus some T&S
Budget	TBC
Funding Agency	ESA

Project Title	SST Data Continuity - Continuation of *in situ* validation to provide a common reference for the AATSR and SLSTR SST measurements
Application and/or Underpinning Activity	SST ECV, Ocean, Climate Validation, Data Continuity
Objectives	To establish an *in situ* data record that can be used to adjust the SLSTR measurements to the (A)ATSR baseline
Maturity	SST validation of SST in the Bay of Biscay is reaching maturity and is creating a long-term validation match-up dataset for SST sensors, including AATSR.
Justification	*In situ* validation using ISAR in the Bay of Biscay is required to provide a baseline against which the SST measurements from AATSR and SLSTR can be adjusted, to ensure no offset is introduced into the data record.
Priority	High – data continuity is vital in a long-term ECV dataset
Urgency	Medium – there is still a year of the current contract to run
Project Description	The ISAR *in situ* radiometer has been operated by NOCS on the *Pride of Bilbao* for 4 years, funded by DECC. The project would continue the observations until at least the end of the commissioning phase of SLSTR. The data will be used to validate AATSR, SLSTR, AVHRR and SEVIRI, and possibly other SST sensors, so that the anticipated gap between AATSR and SLSTR can be bridged and both of the instruments can be compared to the same reference *in situ* dataset acquired by ISAR.
Project Schedule	The current phase of the contract ends in February 2010. The next phase would run from March 2010 to February 2012, or longer if the commissioning phase of SLSTR is after this date.
Resources Required	1 engineer full-time, plus ISAR parts for regular maintenance and some T&S to meetings and conferences
Budget	TBD
Funding Agency	DECC (TBC)

Project Title	Radiometric intercomparison of IASI and AATSR
Application and/or Underpinning Activity	Data Continuity for infra-red radiances and SST ECV
Objectives	To intercompare IASI and AATSR brightness temperatures
Maturity	AATSR BTs are calibrated to < 0.2 K and probably to better than 0.05 K at 11 microns. An intercomparison achieved on 1 day has shown good agreement between IASI and AATSR at < 0.5 K at 11 and 12 microns.
Justification	Radiometric accuracy and traceability is very important for both near real-time “nowcasting” and for long-term records. This applies to both radiances/BTs and derived products such as SST, LST, and atmosphere products that are required for climate ECVs. There are now key climate analyses being conducted at Met Agencies which will be build long-term records on TOA radiances for testing climate models.
Priority	High – we need to understand how we might use BTs for data continuity
Urgency	Medium – needs to be completed by AATSR end of life
Project Description	A system would be developed for finding match-ups between AATSR and IASI orbit tracks to within specified criteria. This system should be automated. The algorithm for computing the comparison of BTs and defined outputs would be specified and implemented in software. A monitoring, quantification and visualisation tool would be put in place.
Project Schedule	Project duration of 1 year ideally to start in summer 2009
Resources Required	Scientist to specify algorithms; EUMETSAT/ESA computing/orbit expertise; software engineer
Budget	Estimated as 100,000 KEuros
Funding Agency	TBD

Project Title	Production of an (A)ATSR Aerosol Product
Application and/or Underpinning Activity	Aerosol ECV, Atmosphere, Climate
Objectives	To establish an official aerosol products
Maturity	Projects such as GRAPE, GlobAerosol and work by Swansea University are all producing prototype aerosol products using (A)ATSR data. The time is now appropriate to consolidate the best aspects of these projects and agree on an official aerosol product for (A)ATSR.
Justification	An (A)ATSR aerosol product would exploit the unique dual-view of the ATSRs and could be used to improve the SST product.
Priority	High – need to maintain momentum of current work
Urgency	High – an AATSR AOD product would be a significant development
Project Description	TBD
Project Schedule	TBD
Resources Required	TBD
Budget	TBD
Funding Agency	TBD

Project Title	"(A)ATSR – The Story"
Application and/or Underpinning Activity	Education and Outreach
Objectives	To create a book which is interesting and accessible to the general public, to help improve public understanding of science and engineering
Maturity	The information exists on paper and in the heads of contributors to the (A)ATSR programme.
Justification	The process of producing an instrument and a satellite remain mysterious to most people. By creating a minimally technical book that tells the (A)ATSR story from a human perspective, it is hoped that a few more people will feel engaged with science and engineering.
Priority	Medium – this is not essential for the science but good for outreach
Urgency	High – the people who can contribute to the story are retiring
Project Description	The book would be composed of chapters written from different perspectives by individuals involved in the programme, so chapters could include the PI's story, the engineer's story, the validation scientist's story, the project manager's story, the civil servant's story, the designer's story, the climate scientist's story, the space agency story, the Australian story, etc. Each chapter could be a composite of experience's or just a single perspective, depending on who is willing to contribute. It should include high quality photographs and diagrams as appropriate and each chapter should include a box summarising the technical background of the chapter.
Project Schedule	Start late 2009, for about one year
Resources Required	Small editorial team, multiple contributors of several pages of material, small production team, external publisher
Budget	TBD
Funding Agency	TBD

Project Title	Production of Aerosol, SST and Cloud by Optimal Estimation (PASCOE)
Application and/or Underpinning Activity	Aerosol ECV, Atmosphere, Climate
Objectives	The main objective is to develop a flexible L2 processing chain using optimal estimation techniques that will demonstrate the effectiveness of MERIS and AATSR working in synergy.
Maturity	Builds on the GlobAerosol and (A)RC projects
Justification	Coefficient-based retrievals of sea surface temperature (SST) date back to the 1970s. The technique gives fair results with great computational efficiency, an important consideration for many years, but is inflexible, can be applied only to thermal infrared brightness temperatures and generates few intrinsic quality indicators. An optimal estimation (OE) retrieval would allow the derivation of skin SST and in addition, aerosol and cloud products, which are in a formal sense the best achievable, from all AATSR and MERIS channels which have some sensitivity to the geophysical quantities. The technique is ideally suited to synergy measurements and in addition produces scientifically meaningful error estimates for individual products and quality indicators for the process as a whole, which are a key demand for users. Currently, pixel-by-pixel uncertainty estimates for satellite datasets are not prevalent despite an overwhelming user request.
Priority	High – develops the synergy between AATSR and MERIS
Urgency	Medium – schedule should match Sentinel-3 ground segment
Project Description	This project will build and validate a Level 2 prototype processor to derive SST, aerosol and some cloud properties, particularly cirrus, from AATSR and MERIS Level 1b products by optimal estimation. The technique can be extended relatively easily to Sentinel-3 SLSTR and OLCI products and other multi-mission time series datasets. In particular such techniques are intrinsically scalable and can be adapted to include new viewing geometries, additional channels and new grid sizes without significant changes to the processor architecture. The project will generate self-consistent, physically-based retrievals of SST; aerosol height, optical depth and effective radius; cloud height, optical depth, effective radius and phase; surface albedo; pixel-by-pixel error estimates for each quantity; and quality (uncertainty) indicators for the retrieval process. Further, the products will be validated against in-situ and other satellite measurements.
Project Schedule	24 months, starting in summer 2009
Resources Required	TBC
Budget	Euro 300K
Funding Agency	ESA

Project Title	Analysis of Validation In situ Data for SST (AVALIDS)
Application and/or Underpinning Activity	SST ECV, Ocean, Climate Validation, Data Continuity
Objectives	The objective of this study is to establish a mechanism and associated infrastructure that will provide a transparent system allowing users to generate uncertainty estimates for AATSR and other SST missions using dedicated on-line tools.
Maturity	Builds on UK Met Office work and complements Validation Scientist work
Justification	This activity will implement a system to generate uncertainty estimates for satellite sea surface temperature (SST) datasets based on the use of multi-way statistical analysis following the approach proposed by O'Carroll et al (2007). Using co-locations of three different observation types of sea surface temperatures (SSTs) gives enough information to enable the standard deviation of error on each observation type to be derived. Absolute uncertainty estimates for satellite derived SST datasets are essential for constructing the SST Essential Climate Variable.
Priority	High – reducing the size of the error bars helps to detect trends earlier
Urgency	High – needed for improved trend analysis
Project Description	1. Conduct a review of user requirements for SST uncertainty estimates. 2. Develop the method proposed by O'Carroll et al (2007) to include other satellite datasets, *in situ* observations and validate the assumptions of independence. 3. Design and implement a database of satellite and *in situ* observations dedicated to SST uncertainty estimation using multi-way statistics for the duration of the (A)ATSR mission (1991-present). 4. Assemble data and populate the database 5. Design and implement an optimised set of analysis tools allowing multi-way statistical analysis of the database using the methods described by O'Carroll et al (2007). 6. Test and validate the analysis tools using appropriate test datasets. 7. Design and implement an on-line user interface allowing different options and assumptions to be selected for the uncertainty analysis providing a transparent and open system. 8. Provide a report of activities including recommendations for the maintenance of database and system as part of the SST ECV process.
Project Schedule	24 months, starting in summer 2009
Resources Required	TBC
Budget	Euro 300K
Funding Agency	ESA

Project Title	Evolution of (A)ATSR Processors to implement improvements from (A)RC
Application and/or Underpinning Activity	SST ECV, Ocean, Climate, (A)RC, SLSTR data format Archive, Data Continuity
Objectives	The objective of this study is to identify the steps that need to be taken to adapt the current version of the (A)ATSR processors to a version that will be capable of generating SST products using the methodology being developed by the (A)RC project. This corresponds to the planned evolution from Version 2.1 of the archive to Version 3.0.
Maturity	Builds on (A)RC project, (A)ATSR Archive Product Processor and work being performed under the SLSTR algorithm development contract.
Justification	This activity will set out the steps that will be needed to implement a system to generate, amongst other things, the improved cloud clearing for the SST product currently under development by the (A)RC project. This is the product that users will wish to use in the future and which is already required by the Met Office Hadley Centre for use in their climate analyses. The results of the study are needed to enable the funding agencies to evaluate the most cost-effective way to develop the (A)ATSR/SLSTR ground segment in readiness for the Sentinel-3 era.
Priority	High – this is the next step in improving SST for climate research
Urgency	High – the analysis is needed before commitments are made on the design of the SLSTR processor
Project Description	1. Review the design of the existing (A)ATSR processors and the existing (A)RC processor to identify areas that would need to be redeveloped to accommodate (A)RC algorithms. 2. Identify any changes that would be required to the L2P product format or annotation data, to accommodate the Version 3.0 SST product. 3. Review the SAFE format that will be adopted by SLSTR, to evaluate the additional changes that would be required to reprocess the existing (A)ATSR archive into the new format for a Version 4.0 archive. 4. Prepare a report summarising the technical issues, and offering options and recommendations for the development of processors to generate the Version 3.0 and 4.0 archives. 5. Provide estimates of the cost of each of the options described in (4).
Project Schedule	3 months, starting in autumn 2009
Resources Required	Existing experts from the (A)RC, DEC and SLSTR projects
Budget	Euro 50K (TBC)
Funding Agency	TBD