ATSR and SLSTR Exploitation Plan

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1 EXECUTIVE SUMMARY

The ATSR Exploitation Plan (AEP) has served the Along Track Scanning Radiometer (ATSR) community, particularly the funders and the science community, since 2009. This revised version of the AEP sees it renamed as the ATSR and SLSTR Exploitation Plan, recognising the significance of the launch of the fourth instrument in the ATSR series (the Sea and Land Surface Temperature Radiometer or SLSTR) and the greatly increased use of ATSR-type data in operational services. It is therefore fitting that SLSTR is a key instrument on-board the Copernicus Sentinel-3 satellite. The term "ATSR series" of instruments refers to all four instruments.

The area of climate data remains crucial to the exploitation of ATSR and SLSTR data, indeed the utility of SLSTR data for climate gives a special importance to its observational capabilities and renewed significance to the development of improved algorithms. Likewise, improvements to SLSTR processing will demand consistently processed data for the three ATSR instruments and the generation of products which enable gap bridging and gap filling between AATSR and SLSTR for the various climate records. The gap between AATSR and SLSTR will be at least four years.

A vindication of the ATSR programme, initiated in the 1980s, was the inclusion of ATSR SST data in the IPCC 5th Assessment report. ATSR climate-quality SST data is world-leading in its characterisation and quality assurance, has provided a fundamental and independent verification of the representativeness of climate SST data, and enabled corrections to the historical in situ SST record. The DECC Chief Scientist and others have noted the importance of ATSR-type climate data to climate strategies and climate policy. The imperative for this is as strong as ever and has grown during a time of an apparent hiatus in global temperatures followed by an developing strong El Nino event through 2015. It is very important that there are specific investment routes ensuring that necessary climate data sets are generated in time for key deadlines, including the IPCC 6th Assessment Report. For the ATSR series, the number of climate-related data sets has been increasing rapidly: sea surface, land surface, lake and polar surface temperatures; aerosols and clouds; land surface reflectance and fires; snow cover. Of these, only sea surface temperature is very mature in its time records although arguably aerosols and clouds are approaching a similar status. A roadmap for the development of polar temperature time series is required, accounting for the complexity of both Arctic and Antarctic environments. Further research and development will be required to bring all ATSR climate data to appropriate quality in the next few years.

The AEP identifies key priorities for ATSR climate data which are of significant import for global climate observing systems (GCOS) and need serious consideration; a climate data generation system which is "operational" for SLSTR and can reprocess back through the ATSRs in a consistent fashion; dedicated support for the creation of long time series for surface temperatures beyond SST (land, lakes, polar); short-term gap filling and gap bridging projects covering essential work to link the ATSR and SLSTR time series; publication of fundamental climate data records (FCDRs) for radiances and reflectance (with uncertainties on radiances and high quality cloud flags); direct comparison and testing against climate models; consistency of the different CDRs including aerosols and clouds. Good co-ordination between the funders, and also between the delivery partners, is required to ensure maximum effect. Funders also need to support creation of climate data services involving generation of ATSR products.

Activities on climate data will necessarily support domain-specific applications of the ATSR series. However, there are also increasing drivers from the science and from service applications which can use either climate quality data or other operational non-climate data, and there are new or emerging products which meet challenges in a number of different areas. A particularly fruitful area is likely to be the combination of ATSR and SLTSR with other satellite instrument data sets (and also other data sets).

These points are well illustrated by the use of ATSR and SLSTR data for **the ocean**. Major features have been the use of ATSR data for operational oceanography through GHRSST and supply of data into this route must occur for SLSTR. Great additional value, especially but not only in the SLSTR era, is achieved by synergies with AVHRR data. Opportunities increasingly exist to ensure SST data are used in combination with other data sets such as altimetry and ocean colour to characterise features such mesoscale eddies, fronts and currents. A sea ice detection product should be developed and could integrate into game changing datasets for the poles.

Land research with ATSR has expanded recently in the last few years and will be a focus for SLSTR alongside ocean data. The improved geolocation of SLSTR compared to ATSR will be a spur to further developments of land products. Key data sets which should be supported include surface reflectance (with further derivation of vegetation indices), land surface temperature, improved fire detection and lake water surface temperature; there is also the possibility of developing surface radiation products, such as photosynthetically active radiation and surface broadband fluxes, which could have important applications. The current activities to make land data products available on bespoke data portals is to be encouraged, alongside further development of thematic portals focussing on regional and megacity scales (e.g. lakes, cities, agriculture).

Interfacing to both ocean and land domains, **knowledge of the cryosphere** provides demanding and exciting challenges with well-known interest for the public, for understanding of natural hazards and for economic development. Whilst relatively unexplored with ATSR data, use of SLSTR for sea-ice detection and temperatures, snow cover and land ice temperatures could have great impact.

Research into the atmosphere using ATSR data has been largely focussed around aerosols and clouds. Greater weight needs to be put on studies which: diagnose these fields and lead to estimates of derived quantities such as aerosol type (black carbon, dust etc); develop techniques for interpretation of the data; cement methods for testing models against the data particularly for clouds;; provide a robust interface to applications such as volcanic eruptions, air quality and dust outflows. Recent work has also established novel approaches to retrieve water vapour, polar wind vectors and cloud top height from ATSR data. It is important to ensure that SLSTR products are routinely produced and that new consistent products are supported and made available to the community.

The first three ATSRs were research instruments and it is a mark of their success, particularly that of AATSR, that the data have been increasingly in demand for **services and applications.** Indeed in writing this plan, the detailed descriptions of these applications have been integrated with the science description of each domain. During the AATSR mission, the most important services developments were OSTIA feeding the weather forecasting models at the Met Office and ECMWF and Met Office/Coperncius operational oceanographic services; the GHRSST data services supporting global operational oceanography and ARC-lake/Globolakes supporting historical lake analysis. These and new services, such as GlobTemperature, should be properly underpinned through SLSTR which will deliver an operational series of instruments through to 2030.

In conclusion, there are huge opportunities for exploiting ATSR and SLSTR data. The necessary activities have been identified and would be game changers in generating long-term data sets for climate and environmental changes, and impact through services and applications.

2 INTRODUCTION

2.1 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 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), managed by the European Space Agency (ESA) and funded as part of the EC Copernicus programme; Sentinel-3 is expected to be launched in late 2015 or early 2016. 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.

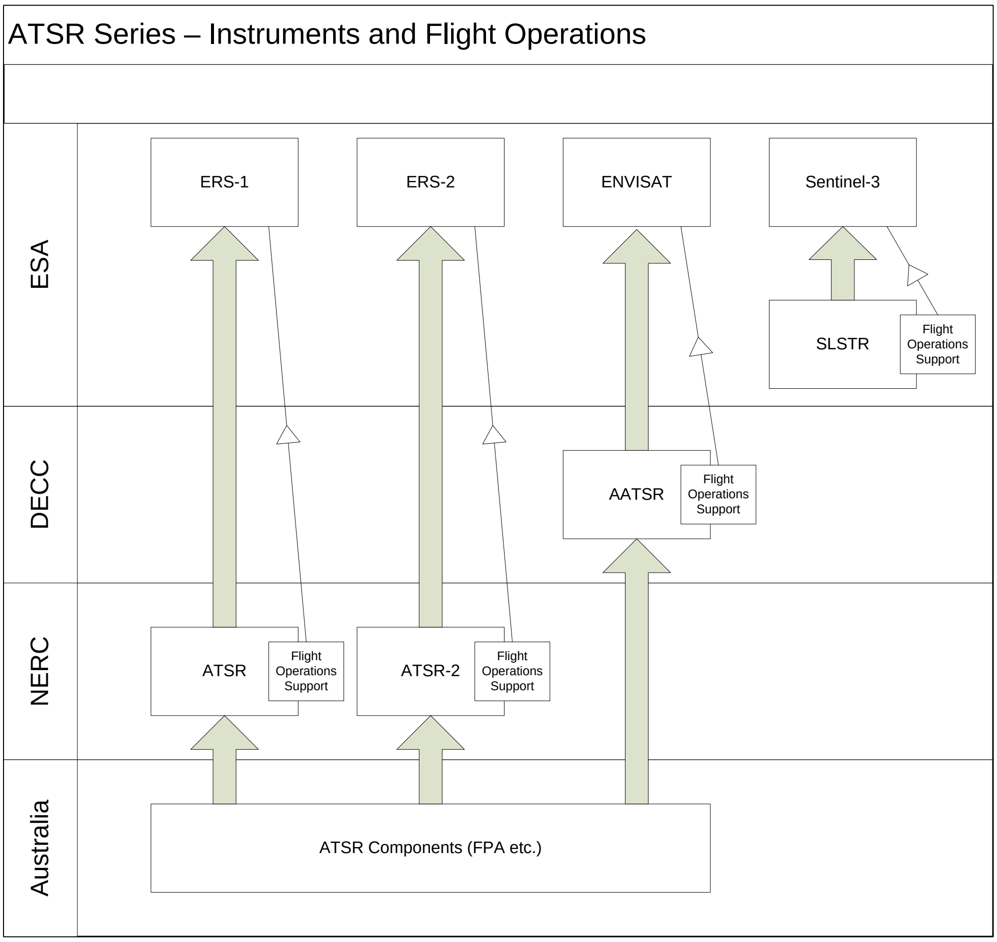

Figure 1-1: ATSR Series - Instrument Providers

The primary role of the ATSR series has been to make very accurate measurements of sea surface temperature (SST). Allen et al, 1994 [RD001] initially and then Ohring et al, 2005 [RD002] identified requirements for longevity of record (the former), bias and stability (the latter). Bias and stability of 0.1 K and 0.04 K per decade are exacting [RD002]. 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 two-angle (dual) view of the Earth's surface and excellent optical design. 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 had 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 initially, 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 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, a land surface temperature product, a lake surface water temperature and offline cloud/aerosol products. These have been strengthened 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 ATSR Quality Working Group (QWG). The fourth reprocessing of ATSR data will produce a level 1 data set in SLSTR format laying the basis for consistent processing. The portfolio of ATSR products is much stronger and diverse than it was ten years ago.

In addition, the development of the ESA Climate Change Initiative has galvanised joint working on significant climate data sets with teams from other instruments. The primary ATSR data sets in this Essential Climate Variable (ECV) activity have so far been SST, aerosols, clouds and fire products.

With the expansion of the product suite, the availability of consistently-formatted ATSR archive and the impending launch of SLSTR, it is timely to consider the further exploitation of the ATSR series of instruments by the community. The purpose of this ATSR and SLSTR 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 underpinning and extension of the ATSR/SLSTR product suite and user base. Furthermore it will point to the exciting potential for co-utilisation of ATSR-type data with those of other instruments on Envisat and a number of significant satellites in orbit at the time, and with satellites available once SLSTR is launched.

2.2 Heritage of the AEP

The AEP is based on an earlier document, the ATSR Science Exploitation Plan (SEP). The ATSR Principal Investigator (PI) and his team, together with the 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, at the time) 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, provided 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 ATSR programme.

The previous version of the AEP was published by ESA as ERSE-DTEX-EOPG-09-0003, dated 15 May 2009.

2.3 Aims of the AEP

The main aims of this new 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 ATSR-type data.

2. Show how the programme associated with the ATSR series 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. Consider the operational services which have utilised AATSR data and will use SLSTR data

5. Suggest priorities for the future ATSR and SLSTR 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 ATSR data, including:

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

The AEP enables all these users to have a global picture of ATSR and SLSTR 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 can seek funding for their research activities and receive endorsement if their activities are listed in the AEP
- The community can see ATSR activities in an overall context and synergy can easily be exploited (fast progress in the life cycle from science, applications, operational use)

The growth in ATSR data sets means that the ATSR programme has needed to provide clear guidance and signposting to datasets. The ATSR sensors website is of particular utility for this, and allows an easy means of describing recognised ATSR data sets with clarity.

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 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 ATSR series of instruments. Responsibility for maintaining the AEP will rest with the ATSR Exploitation Board (AEB), as described in section 2.6.

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 ATSR and SLSTR data, by outlining the scientific research and operational activities that are most significant and worthy of funding by one or more of the existing or potential appropriate agencies to achieve the intended improvement.

2.4 Format of the AEP

This AEP now provides in one document the essential points for the AEP whereas originally the AEP had five further volumes. It contains an expanded set of Chapters (4 to 8) to cover all domains and summarise the main scientific and operational thrusts.

This document is also intended to complement the material in the 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 ATSR Validation Scientist (PI) and is available at http://www.leos.le.ac.uk/aatsr/howgood/validation/documentation.html .

2.5 Format of the AEP

The new AEP is split into six sections:

1. Executive Summary.

2. Introduction

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

3. Policy areas

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

4. Relevant Scientific Research and Operational Applications (chapters 4 to 8)

   This section describes scientific research which is necessary to provide a sound basis for the development of the ATSR applications as well as the products that are needed in each application area. This is the type of activity traditionally coordinated by the ATSR Science Advisory Group (SAG).

5. Operational Applications

   This section summarises 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. Further details of operational applications are in each chapter.

6. 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.

2.6 Strategy for updating the AEP

The AEP is intended to set a framework for the development of ATSR-type 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 on possible priorities for the funding partners in the context of AATSR's excellent performance, the seventeen year archive of ATSR data, and the opportunities afforded by the SLSTR.

The AEP will be developed in response to the requirements of the ATSR Exploitation Board (AEB), which has overall responsibility for the development and maintenance of the plan. It is anticipated that the plan will be updated on cycle of approximately five years and will be freely available on the ATSR Sensors website (www.ATSRsensors.org).

The AEP complements other documents and web-based material that describe the ATSR-1, ATSR-2 and AATSR projects in detail. These are accessible through the ATSR Sensors website. Appendix B lists the current set of ATSR products, for ease of reference.

2.7 The ATSR Exploitation Board (AEB)

As stated above, the AEB has 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 ATSR-type data can be achieved, to the mutual benefit of all parties.

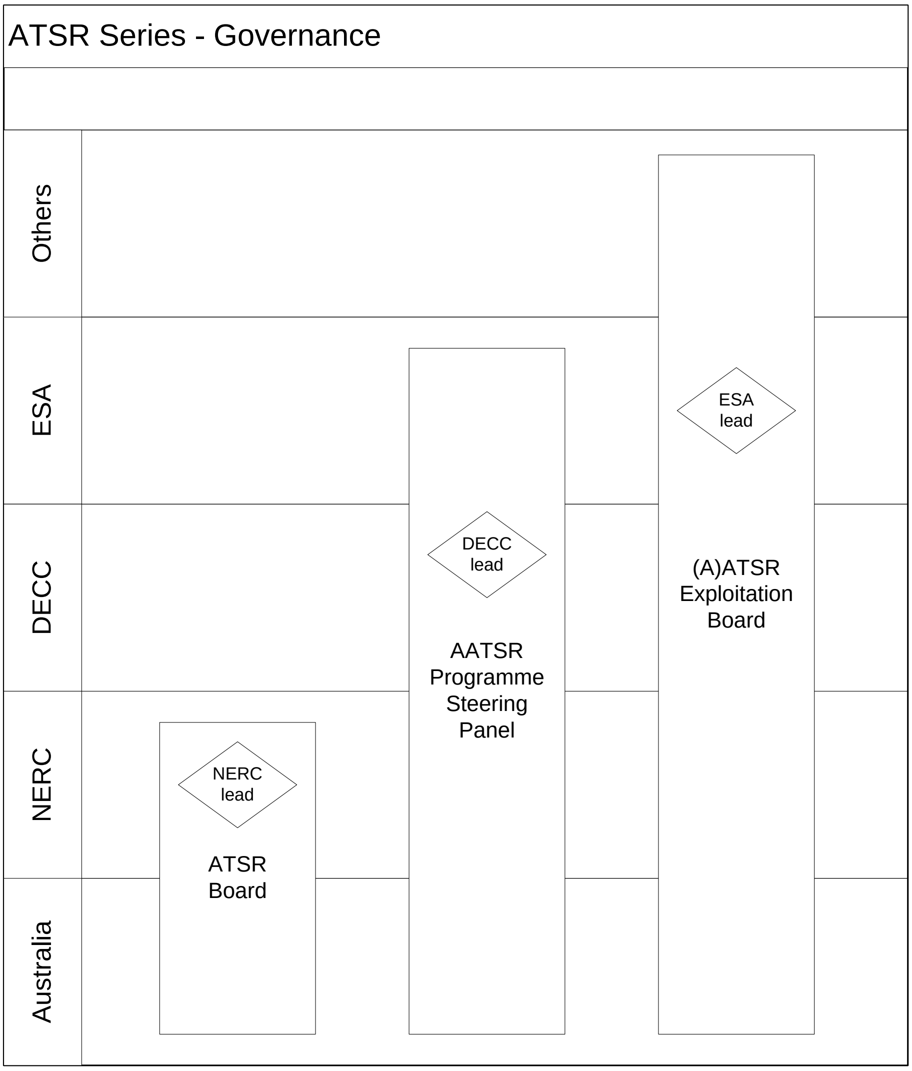

Figure 1-2: ATSR governance

The AEB is supported in its task by various bodies:

1. The ATSR Principal Investigator Team
2. The ATSR Science Advisory Group
3. The ATSR Quality Working Group
4. ATSR Users

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

The ATSR Principal Investigator Team

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

2.7.1 The ATSR Science Advisory Goup

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 ATSR programme have been provided by the ATSR SAG, which is sponsored by DECC and supported by all the other funding agencies.

The SAG agreed to form topic teams to support the development of the AATSR Science Exploitation Plan according to the following topics: (chapter numbers)

4. Climate research and prediction
5. Ocean processes
6. Land surface processes
    i. Land Surface Temperature
    ii. Fires
    iii. Lake Surface Water Temperature
    iv. Land Surface reflectance
7. The atmosphere
8. The cryosphere
9. Operational applications for ATSR and SLSTR, 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 evolve into a new scientific body that provides science advice on all the ATSR-type instruments including SLSTR. The exact mechanism for this to happen is to be formulated by the AEB and the ATSR science team.

2.7.2 The ATSR Quality Working Group (QWG)

The ATSR QWG is charged with improving the quality of the 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 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, supported by a Mission Performance Centre which has just been formed. A formal link to the AEB has yet to be formulated.

2.7.3 ATSR Users

The wider user community will be encouraged to use ATSR-type data and feedback their comments and recommendations to the Science Team, QWG and AEB, as appropriate. FOR SLSTR data, users will also be able to provide comments to the Sentinel 3 Mission Performance Centre (MPC). Operational users will be represented directly at bodies such as the AEB by the Copernicus operational service and GHRSST.

2.8 Scientific Research and Operational Priorities

The information from 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 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 of performance and its exceptionally low-noise images.

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 and operational priorities to be addressed by ATSR were grouped above 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. A synthesis of operational requirements is provided in Chapter 10.

It will be seen from this document that climate change research inevitably overlaps substantially with the other categories. Also, the number of applications for ATSR-type data is increasing and operational use of SLSTR data is significant in all categories. Finally, of these five categories, investigations of the land with 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 ATSR exploitation programme.

Chapters 4 to 8 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 Chapter 4.

3 POLICY AREAS

3.1 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 part of the evidence for the policy decisions needed to mitigate and adapt to adverse environmental changes, including climate change By providing driving data for models and by pointing to model updates, the datasets further add to evidence through model predictions. 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 ATSR data can make a significant scientific contribution.

3.2 Climate change

3.2.1 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 in the ranges 0.3°C to 1.7°C, 1.1°C to 2.6°C, 1.4°C to 3.1°C, 2.6°C to 4.8°C, depending on the projected 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. These concerns have already resulted in actions through the United Nation Framework Convention on Climate Change and its associated Conferences of the Parties. One consequence has been the establishment of the UK Climate Change Act 2008 with associated benefits and costs of the order of hundreds of millions of pounds between 2008 and 2050.

As part of the evidence and monitoring of this policy, there is a clear need for improved diagnostics of the spatial and temporal patterns of global and regional temperatures. We also need to understand other elements of changes in the climate system. From an ATSR point-of-view, 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. How are other (non-CO_2) forcing factors for climate changing?
5. What type of political action might help to mitigate these changes?
6. What political actions are required to adapt to climate change?

Clearly, ATSR-type 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 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 ATSR measurements can make a contribution are listed in Appendix A. An effective strategy for the ATSR programme to follow would be to concentrate efforts on developing and refining the ATSR data products which are relevant to that list.

3.2.2 Science requirements for ATSR to support climate change policy

One important indicator of climate change is global SST and 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

ATSR data 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 ATSR. However, other geophysical parameters measurable by the 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 ATSR calibrated radiance data themselves contain information on changing radiation values. All these ATSR products need to be developed and combined with other suitable sources of data to produce robust ECV climate records as summarised in Appendix A.

3.3 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 systems for the ATSR series of instruments meet the needs and objectives of policy-makers.

3.4 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 ATSR data might include:

- urban planning (land surface temperature observations of ‘urban heat islands’)
- air quality (aerosols, land surface temperature, fires)
- land use management, in agriculture, forestry and change-of-use issues (land cover monitoring using AATSR reflectance channels, fires)
- 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 ATSR data exploitation programmes develop.

4 CLIMATE RESEARCH AND PREDICTION

4.1 Introduction

The principal objective, and indeed core, of the ATSR programme has been to produce independent climate-quality data of relevance to the monitoring and diagnosis of climate change. The ATSR programme has achieved this and the expectation is that the SLSTR instrument will continue this role at a crucial time for observing surface temperature change.

The focus of the ATSR programme has been on sea surface temperature (SST). In fact all three ATSRs have contributed to the satellite climate data record for SST, and recently progress has been made on data from the early Pinatubo years of ATSR-1. The evidence for SST change from the ATSR data was included in the IPCC Assessment Report (AR5) for the first time. The SLSTR data will add to this record with the goal of greater daily coverage and more than one instrument operating in space simultaneously.

In recent years, a fundamental shift has taken place in ATSR science for climate. The maturing of aerosol and cloud data from ATSR as longer-term records has been swiftly followed by lake surface water temperature (LSWT) and land surface temperature (LST), as well as long-term records for fire. The ATSR missions are now well-known for at least six long-term variables and indeed surface reflectance records are also long-term (but have been paid less attention).

An additional factor in ATSR climate data records, aided by this broadening of the thrust of ATSR-related climate science, is the development of stronger regional, multi-domain analysis most notably for the Arctic.

4.2 What are the strategic scientific issues?

Climate science has been a key pre-occupation of researchers and government for some decades now, and this is the reason that DECC has supported the ATSR programme. During that time, there have been periods where surface temperature records have not been to the forefront of science (although still very evident in the public eye). At the current time, it is the opposite. The surface temperature records are raising some fundamental questions about climate and observing current surface temperature has arguably never been more important. In climate science, there has also been an increasing focus on multi-variable analysis, whether it be for detection and attribution, or for emergent constraints on model predictions of change over the next century. Key issues are:

a. At a time of global temperature hiatus, how will temperatures over the next few years evolve?

b. Can we differentiate between surface temperature changes of the sea, land, and lakes?

c. Does the pattern of SST changes or assimilation of SST into models provide diagnostic skill in terms of understanding of the apparent global hiatus?

d. How are polar surface temperatures and snow/ice extent changing and can records of surface temperature achieve sufficient accuracy, and estimated uncertainty, to provide a confidence in a consolidated time series and to allow differentiation of domain effects?

e. Can we develop the first climate-quality dataset for LST.

f. Can we improve historical temperature records further through analysis of modes of surface temperature from the satellite-era.

g. Can we produce consistent global air temperature records across domains.

h. Can we deliver aerosol and cloud data records of climate quality with gap filling to SLSTR.

i. How do we improve analysis of lake surface water temperature (LSWT) records in conjunction with the user community.

In many ways, the key topics are clear because of the fundamental nature of the challenge that the ATSR programme has been confronting from the design of the first instrument. What is different is that the quality of the data records have now improved considerably and the interpretation of the datasets have matured. It was a particularly significant step for the ATSR SST record to be evidenced in the IPCC Fifth Assessment Report, and for it to demonstrate that the improved in situ record is very consistent with satellite datasets.

The apparent global hiatus in surface temperature rise, followed by an El Nino, places an increased emphasis on careful examination of SST data and in undertaking increasing regional analysis to identify footprints. Working with modellers through assimilation of SST should also offer a valuable way to bring data and models together.

A major story in the last decade has also been the reduction in polar sea ice, aided by severe meteorological factors in 2007. A concomitant change in polar temperatures has been observed but with spatial variations not captured by models. It is a pressing issue to understand whether such temperature change is uniform or variable across domain as seems to be the evidence so far. A further challenge observationally is that this requires ice and snow surface temperature retrievals.

Long-term changes in lake surface water temperature have been observed and comparisons reported but now need to be in the context of local environmental change and regional climate change. What do we expect? Will the records be consistent from local to satellite observations?

Land surface temperature offers much promise to fill in temperature changes for the 30% of the globe that is land. Although not formally declared as a primary ECV as yet (but it is a secondary ECV), LST is providing very useful information and is approaching climate-quality.

The needs of the climate modelling community and the more dynamic nature of the processes to be encapsulated means that there is great interest in complementary satellite datasets for different variables, for example including aerosols and clouds particularly around their life cycles and climate feedbacks. The challenge is to ensure that the variables are addressed coherently and that the ATSR programme plays a role in the future usage of the data.

An urgent issue, but one which is being addressed in part, is the need for operational climate datasets to underpin the evidence base for science and policy. The need for quality-controlled and assured data for key variables has been well articulated, and is especially true at the current time. We have a renewed sense of the need for well-estimated uncertainties for climate data which provide an intrinsic context to interpretation of the data. The EC Copernicus Climate Service will provide an answer in part, building on the success of the ESA Climate Change Initiative (CCI) programme, but individual countries will need to contribute their own efforts to ensure their needs are fully met and to continue to guide the development of climate data records.

4.3 How can ATSR contribute?

The ATSR instruments are already contributing to climate data needs and assured of continued importance with the launch of the next instrument in the ATSR series, the SLSTR. As indicated above, there are at least six variables for which ATSR data are relevant and leading. The ATSR programme as a whole provides an important forum for promoting climate data needs from research communities and government, and for understanding the datasets that are being produced through these efforts. The ATSR instrument data therefore fundamentally contribute to this area which is ATSR's primary goal.

The SLSTR instrument will provide an important extension in time but also in capability as discussed below.

Further discussion of each variable can also be found under the domain-specific sections of the AEP.

4.3.1 Direct uses of ATSR and SLSTR data for climate

The direct use of the ATSR dataset is exemplified best by the SST case where the independent ATSR climate data record has achieved three things: firstly, shown the quality of the in situ record over the oceans and the substantively correct form of it; secondly, highlighted corrections which need to be made to the in situ record which has improved the in situ record back into historical times; thirdly demonstrated good coverage of the oceans globally with realistic uncertainties thus allowing fingerprinting of surface temperature change and derivation of modes of variability which could improve historical reconstructions. The ATSR SST dataset has confirmed the global hiatus, although only up to 2012 due to the failure of Envisat. This illustrates the need for continuity of sensors (see gap filling section below).

For SST, the SLSTR instrument will return dual-view capability to the integration of all SST data, in other words to the accuracy and robustness which are very important for climate. It will also provide greater coverage than for ATSR, for the first time combining the swath advantages of AVHRR with the climate accuracy of ATSR; studies have shown that coverage is an important component of uncertainty for averaged SST data.

A step forward with SLSTR will be the operational production of LST data and potentially lake surface water temperature (LSWT) data, allowing a better basis for bringing datasets to climate quality. There is no doubt that SLSTR data will be an important contribution for the climate community, as indeed will all the data from Sentinel-3. Equally, it is also the case that operational data is not likely to prove suitable immediately for climate data and dedicated work, unplanned at present, is likely to be needed.

For aerosol and clouds, ATSR data are already being used for investigations of long-term change and new ATSR datasets are being produced through the ESA CCI programme. The SLSTR series will provide a welcome extension of the time series and could potentially provide some improvements in quality of cirrus cloud data (new channels) and aerosol data (improved spatial resolution).

Fire data will also be improved via improved fire channels with the production of fire radiative power for the first time from the ATSR series, and improved burnt area. The continued provision of a world fire atlas needs to be considered, as it would allow seamless viewing of fire changes linking the ATSR and SLSTR eras.

For all variables, the SLSTR data will provide an important step forward in coverage which means a better statistical representation of gridded climate data, and more importantly an opportunity to assess the sampling implications of ATSR climate data.

4.3.2 Synergistic uses of ATSR/SLSTR data (and other sensors)

Synergistic use of datasets is an important tool in the scientific armoury and for climate it has become an intrinsic part of the development of long-term data sets. The key reasons are to improve spatial sampling, to ensure good inter-calibration, to bring necessary resolution of temporal (diurnal) variations and to make optimal use of all primary sensors for a particular variable.

For SST, the key aspects are to improve spatial coverage, to fill gaps in time series and to extend data back in time. Diurnal variations are mostly small and coverage for climate applications is a lower priority, although it is important that time series are at common local times. The focus of activities has so far been on improving the AVHRR record using the quality of the ATSR data; AVHRRs are operational instruments and offer time series of data back to the mid-eighties.

For other data sets the climate synergies are different. A climate LST record, although not yet available, needs good coverage as for SST but also careful treatment of diurnal change. Daytime and nighttime LSTs are very different and so the two cannot be merged. Therefore, the use of other data sets such as MODIS is good for spatial coverage and geostationary data, particularly from SEVIRI, may be used to resolve diurnal influences. For lake surface water temperatures, there are corresponding products from MODIS and AVHRR. The intercomparison is revealing but much further work needs to be done before synergistic use. Likewise for ice temperatures (whether land or sea ice).

For aerosols, clouds, surface reflectance and fires, there has been less synergistic work but there is probably much to be gained from linking data sets to obtain more holistic descriptions of parameters (aerosols, clouds) or to give confidence in products (surface reflectance and fire).

Finally, as the quality of data improves so there has been more synergistic applications to climate state interrogation and testing of climate models. Promising combinations include use of sea surface heights from altimetry alongside SST to test estimates of sea level rise and the causes; land surface temperature and soil moisture to test impacts of soil dryness including drought; fire data with atmospheric gas concentrations to look at emission factors for carbon and plume chemistry.

4.4 Operational Applications

There are two principal routes for operational applications of climate data from the ATSR series of instruments.

The first is via national agencies such as the Hadley Centre, and the second is via European level institutes. The Hadley Centre has made increasing use of climate quality SST for HadISST both directly and through OSTIA-type level 4 analysis. The wider swath of SLSTR will be of considerable importance for SST coverage, depending on the number of SLSTRs in operation at any one time and the accuracy of the wide swath data. There is considerable potential for increasing use of the other ATSR products and indeed LST and IST are being investigated.

The European level route for operational climate exploitation will now clearly be based around the Copernicus Climate Service which will be primed by the European Centre for Medium Range Weather Forecasting. The primacy of ATSR-type data products will need to be articulated and evidenced if full exploitation is to occur through this service; in contrast exploitation through other services is clear, e.g., SST for the Ocean Service and aerosols for the Atmosphere Service. The European climate service requirements for ATSR-type data sets are not yet clear.

It is clear that the advent of SLSTR will result in long-term demand for climate quality data from this sensor and consequently from the predecessor ATSR instruments. Work is urgently needed therefore on design and implementation of climate data services from SLSTR in particular, and from other Sentinel instruments in general.

4.5 Requirements on data for climate research and prediction

Requirements for data are given below but it is important also to recognise that timely delivery (within 24 hours) is required for some climate services. This is so that the satellite data can be incorporated alongside other data sets when these are available. This mode might be termed short-delay mode although near real-time (NRT) might be required for some data streams.

4.5.1 Product accuracy and availability

State-of-the-art climate data sets require careful retrieval algorithm development, consistent application, error characterisation, and detailed calibrations. For this reason, climate data products take a number of years to come to maturity and of the ATSR data sets, full climate quality data sets are only readily available for SST.

The most accurate SST data sets for the ATSRs are from the ARC project which was supported by DECC and NERC. Typically, SST accuracy is better than 0.1 K for all regions of the global ocean and SST stability for global data is better than 10 mK/year. The data are available from the NEODC as are similar data sets from the CCI SST project.

For aerosols and clouds, data are available on the CCI aerosol and clouds web-sites. There are also previous analyses of data from projects such as Globaerosol but these previous analyses are probably not of climate quality. Although agreement is very good with ground-based remote sensing instruments, the need to use the most recent calibrated visible channel signals and biases due to retrieval uncertainties limit the data sets suitable for climate to the CCI data. For other possible climate products from ATSR-type instruments, these are not yet available although lake surface temperature data are available through bespoke web-sites and a prototype LST climate data record is being produced over the next 18 months.

4.6 Gap bridging and gap filling

Since the Envisat mission ended in April 2012, there has not been a dual-view instrument in space and the next such instrument will be the SLSTR. Hence it will not be possible to obtain full continuity of the ATSR climate-quality record into SLSTR without the use of alternative sensors. The minimum gap in data is expected to be four years. Two concepts are relevant: gap bridging which refers to the ability to tie the ATSR and SLSTR records together in terms of accuracy and stability; gap filling which refers to the ability to utilise alternative sensors to provide data between the end of AATSR and the commissioning of SLSTR, allowing a continuous record albeit most likely with greater uncertainties in the gap period. In other words, •ATSR and SLSTR epochs need to be bridged with satellite data that (1) fill the data void (2) overlap with AATSR and SLSTR to a degree allowing harmonisation of calibration (stability) along the entire time series (ATSR-1 to SLSTR).

Table 1 shows the gap filling options for each climate variable discussed in this section.

Table 1: Gap bridging and gap filling options for ATSR/SLSTR climate observations

Variable	Gap bridging options	Gap filling options	Comments
SST	Radiometric calibration against IASI-A; SST validation against in situ reference radiometers and buoy tropical arrays; SST against Metop-AVHRR, possibly MODIS. Back-up: radiometric calibration, IASI-A vs AATSR; IASI-B vs IASI-A; IASI-B vs SLSTR; SST as above	Use AVHRR on Metop-A (9.30 orbit); correct AVHRR biases with IASI, homogenise BTs. Back-up: use MODIS SST data or ideally data processed in a consistent manner from MODIS L1	Needs very good understanding of Metop-AVHRR biases against AATSR and stability of IASI-AVHRR radiometrically corrected BTs. Likewise for MODIS.
LST	Similar for radcal under SST section. Possibly use AVHRR but calibration questions. Anomaly verification against MODIS/SEVIRI Validation against LandSAF/KIT in situ African radiometers	Use merged product from GlobTemperature which will include MODIS data, bias-corrected	Difficulty with LST is that differences in satellite overpass time cause problems with continuity of time series (strong variations of LST even in 30 minutes). Both AVHRR and MODIS are challenging.
Lake surface water temperature	Validation against Lake Tahoe site and in situ lake data	MODIS/AVHRR data	Uncertainties may be lower for regions with lake validation data
Aerosols/ clouds	Metop-AVHRR data.Validation against Aeronet (for aerosols);	MODIS data	Depends on length of gap and whether MODIS continues to operate.
Surface reflectance	MODIS data (from GlobAlbedo studies). Possible MISR data	MODIS data	Depends on length of gap and whether MODIS continues to operate.
Fire (counts) Fire radiative power	MODIS data SEVIRI data MODIS data SEVIRI data	MODIS data Not applicable as ATSRs did not have capacity for this product	Could use Metop AVHRR but only minor testing and no operational product. However MODIS algorithm and performance different to ATSR SLSTR will be first ATSR-type sensor with this product
Snow extent	MODIS data	MODIS data	Characterisation of ATSR snow extent data against MODIS data requires further work.

4.7 Recommendations for future work

1. A collaborative ground segment should be implemented (Surface Temperature and Temperature Synergy - STATS) for the key ATSR climate quantities. This could be part of a wider Climate Data Centre in the UK.

2. UK agencies and European partners should invest specifically in climate data analysis of SLSTR to ensure that the climate data records are available with minimum delay for the successor climate assessments to the IPCC's 5th Assessment Report. There needs to be close liaison between scientists working on algorithms and validation for climate-quality and operational agencies such as ESA and Eumetsat.

3. Investigations of clear-sky versus under-cloud SST differences should be performed.

4. The first long-term climate records of LST and polar ST should be produced. Fire data also need particular attention.

5. Surface air temperature relationships with satellite surface temperature measurements should be derived for all surface types.

6. The consistency of aerosol and cloud identification should be investigated in ATSR products (SST, LST, Aerosol and Cloud).

7. Gap filling strategies need to be implemented and work supported in the time preceding the commissioning of SLSTR.

8. There is a clear imperative for closer testing of data against climate models: joint initiatives with climate modellers should be developed.

9. The development and application of direct radiative testing from climate models should be encouraged for ATSR/SLSTR.

10. Publication of Fundamental Climate Data Record (FCDR) information on thermal infra-red radiances and visible channel reflectances should be encouraged and supported.

5 OCEAN PROCESSES

The ocean provides a strategic challenge for satellite data, which aside from gravity (geoid) measurements, can only access the sea surface and with varying spatial coverage due to orbit swaths of individual instruments. Some of the key progress in using satellite data for ocean studies is occurring through synergistic use of sensors, through use of data for boundary conditions for ocean models or by assimilation of satellite data into ocean models. The drive towards greater spatial resolution in ocean models is providing a better platform for comparing such models with the high spatial resolution (1 km) of the ATSRs. There is also high value in the use of satellite data for climate studies as discussed in the relevant section.

5.1 What are the strategic scientific issues?

Oceans transfer significant amounts of energy through the Earth system, driven by the thermohaline circulation and surface currents. The intensity of regions of upwelling and downwelling influences current strengths, providing coupling between the ocean and atmosphere in heat, moisture and carbon (through interactions with phytoplankton). Fronts are particularly sharp focal points for air/sea interactions. Ocean eddies provide more isolated surface current regions for transport of water masses and for mixing in the vertical. Ocean waves transport momentum and heat from one ocean sector to another. The driving of tropical convection over ocean is a particular example of strong SST forcing of the atmosphere. There is no doubt that SST departures for climatology influence atmosphere circulations from the large-scale to coastal breezes. All of these phenomena are important for operational oceanography, for improved weather forecasting where ocean-atmosphere coupling is significant, for understanding changes in regional ocean characteristics, and for improving knowledge of the genesis and fate of the large-scale phenomena affecting climate such as El Nino. Into this complex system, we can add freshwater and pollution influences through changes in ice and river discharge, as well as the role of maritime storms in the atmosphere such as hurricanes and tropical cyclones.

5.2 How can ATSR contribute?

5.2.1 Direct uses of ATSR and SLSTR data

The ATSR data have contributed strongly to analyses of SST data which have driven models, including atmosphere only models for numerical weather prediction. ATSR data have been used to analyse long time-scale waves in the ocean. The strongest advances for oceanography will most likely come with SLSTR where the wide swath of the instrument will deliver new benefits, particularly in a two satellite system. Much improved data quality, particularly in cloud flagging, will sharpen the use of data from the ATSRs to study high resolution depictions of currents and eddies, and to validate models. Further examination of the quality of data in interface regions, such as coastal (e.g. in outflow of rivers) and ocean-ice edge could further improve knowledge of ocean variability in these transition zones and the sources of flux. The ocean is otherwise difficult to observe in a consistent manner with high spatial resolution unless satellites are used. Ultimately the most significant goal is to improve ocean forecasting models.

5.2.2 Synergistic uses of ATSR/SLSTR data (and other sensors)

There are three sets of synergies that are of particular significance for ATSR uses in ocean studies. Firstly, combinations with other SST data sets improve the ability to represent the ocean globally but with good temporal and spatial coverage. The ATSRs provide a calibration bedrock to the SST analyses which are used for operational models and increasingly for long-term climate characterisation (representation of global states). The SLSTR instruments will add coverage. Microwave SST data provide particularly important complementary data sets in terms of cleay sky versus SST under cloudy sky, which would bear further analysis. The analyses such as OSTIA which mathematically combine the different data streams are a very important driver of applications. Further verification of analysis and increased signposting/availability of data could very much increase the utility of the ATSR-type instruments; GHRSST provides a very good outlet for operational users.

A second synergy is with altimetry and models incorporating gravity data to examine currents and provide observational constraints to observed behaviour. The third synergy is with ocean colour instruments to provide constraints on marine plankton development and decay, and hence on biological activity. Research focussed on ecosystem-sensitive areas, for example in the Arctic, could be very important over the next decade.

5.3 Operational Applications

The operational application of SST from the ATSRs has been driven by the GHRSST project and has ensured that such data sets are now produced in harmonised format and available to the global oceanographic and meteorological services. Applications are as diverse as weather forecasting and defence. Ocean services have strong foundations in SST since the temperature of the ocean is fundamental to fishing and tourism industries. For this reason, the Copernicus Ocean service has demonstrated products which utilise ATSR data and will be an important user of SLSTR data primarily in near real-time mode.

In Europe, the development of analyses such as OSTIA has increased the importance of SST data to weather forecasting in a significant manner. Such analyses will make significant use of near-real time data from SLSTR. It is likely that such systems would want to use sea ice detections from SLSTR where available, although microwave data will remain the foundation of sea ice information.

5.4 Requirements on data for ocean processes

5.4.1 Product accuracy and availability

The ATSRs have achieved good accuracy for the first three instruments in near real-time data with improved accuracy for climate in offline data. So the products are very well characterised with low bias and noise. The challenge is to achieve the same with the SLSTR data. Data availability is very good through adoption of the GHRSST L2P format and dissemination routes alongside those of the ESA and DECC archives. The dissemination of data should be equally good for near real-time SLSTR SST data through the Eumetcast system. A clear requirement is to ensure that SLSTR data are available to users in near real-time and offline modes, with a very good connection to GHRSST and to the OSTIA system.

5.5 Gap bridging and gap filling

Gap filling is not as significant for ocean applications, outside of climate, as the OSTIA and other analyses remain as primary sources of observations using in situ and other satellite observations. Work on gap bridging is covered for ocean SST in the climate section and is also significant for wider ocean applications. The important aspect is to use analysis systems to monitor biases in the SLSTR timeframe and compare to biases obtained in the AATSR period.

5.6 Recommendations for future work

The mission drivers for ATST ocean science are operational oceanography, validation and assimilation into models, and synergistic use with other data sets. The recommendations are to:

1. Continue providing outputs of SST in GHRSST format.

2. Continue synergistic product development with AVHRR, through the CCI project.

3. Commission further studies of cloud detection, particularly in high latitudes.

4. Investigate the detection of sea ice from ATSR/SLSTR (c.f. cryosphere); including the synergistic use of other sensor information.

5. Encourage ocean modellers to use satellite SST data, particularly from appropriate synergistic products.

6. Use high-resolution SST directly for current definition and interpretation; also particularly for mesoscale eddy identification and characterisation.

6 LAND SURFACE PROCESSES

The land surface is a complex, challenging but rewarding are for study from satellites. For the ATSR-type instruments, there remains much research and development to be undertaken to really deliver the full potential of these types of instruments for land observations. For SLSTR, this is a primary goal. Whilst challenging, the benefits of accurate information for land science and information systems will be tremendous and hence it is highly worthwhile for the community to focus resource and effort in this area.

6.1 Land Surface Temperature

Land Surface Temperature (LST) is a natural variable for the ATSRs to observe but one which was initially not a target of the mission. It is now rapidly growing in significance as the techniques and underpinning knowledge have extensively improved in the last several years. The impact of LST data is likely to be high because it is relevant to a large number of land surface and land-atmosphere topics both from an observation point-of-view and a modelling perspective. In addition, the quality of LST has improved to the point where it appears to provide climate-relevant information and should become a primary ECV.

6.1.1 What are the strategic scientific issues?

Knowledge of LST is already being exploited in a number of key areas. The major strategic scientific issues for LST are concerned with:

a. Land temperature change for climate

b. Land surface change

c. Heat and gas fluxes

d. Soil moisture states

e. Conditioning for onset of fires

f. Vegetation phenology

g. Monitoring and modelling of lakes

h. Improvement of lake/near-lake forecasting

i. Assimilation of land products into models.

The strategic scientific issue for land temperature from a climate perspective is to establish a climate quality time series of land temperatures in the long-term (>20 years) with high stability. Aside from the direct monitoring of land surface temperature change, this is in order to act as a sensitive indicator of regional climate change and variability whereby interannual and seasonal variability can be identified from long-term time series such that one can pick out the signals of large events such as the El Nino Southern Oscillation (ENSO). By examining the relationship between regional LST and other variables such as Normalised Difference Vegetation Index (NDVI), the phenology of such change could be studied. One would also want to quantify the relationship with land surface air temperature (LSAT), which has been shown to be non-linear and land cover specific, with the aim of informing on the accuracy of LSAT interpolation across sparse regions without meteorological stations; and gap-filling the LSAT record over such sparse regions.

There is a wider perspective also. Land surface models are important in their own right but also as part of Earth system models, integrating the different domains of Earth. Next generation Earth system models will have interactive land surface models for carbon. LST is useful for the evaluation of land surface models, and in their improvement (via data assimilation) where models are known to have problems.

Furthemore, the need to understand temperature regimes in sparse regions is a requirement for improved Ice Surface Temperature (IST) both for sea-ice, land ice and ice, and indeed to confront the challenges of surface temperature retrieval along the transition zones between domains such as the marginal ice zones, coastal zones, permafrost and lake edges.

The strategic scientific issue for land temperature from a perspective of health is to determine relationships between human health and temperature variability. In cities during heat waves increased health problems have been correlated with high night-time urban temperatures – the aim should be to investigate these relationships and provide robust scientific data to support urban planning and risk assessment. LST and LSAT have also been shown to be significant factors in disease vectors and their epidemiology – an example being Malaria infection rates; the aim should be to provide high quality temperature data so as to accurately quantify these relationships for potential stakeholders such as the World Health Organisation (WHO).

The strategic scientific issues for land temperature from a hazards perspective is in the identification and mapping of both pre- and post- thermally anomalous land surface features, such as those associated with active volcanoes, and in determining fire risk. The latter involves the derivation of ratios of LST and NDVI in addition to meteorological inputs in modelling surface dryness. The aim should be to investigate the structure of the algorithms for difference land cover types.

The strategic scientific issue for land temperature from an ecological/geographical perspective is to link LST and plant health and function to their ecological and climatological responses. This requires understanding the correlations between canopy leaf temperature and other indicators of plant health and function such as fluorescence and biogenic emissions. LST could thus be exploited as a proxy for such variables in driving models of ecological and climatological responses. Existing work, such as the ESA Water Cycle Multimission Observation Strategy (WACMOS) project has exploited LST from AATSR to determine the soil water control on evapotranspiration (ET) for selected regions. The aim here should be to capitalise on such applications of LST to produce regional and global datasets of ET for interrogating models of land/atmosphere coupling.

6.1.2 How can ATSR contribute?

6.1.2.1Direct uses of ATSR and SLSTR data

The ATSR and SLSTR instruments can contribute through direct observations of LST; indeed the SLSTR instrument has been designed specifically with LST in mind. Current work focusses on accurate, stable measurement of land surface temperature at medium resolution, development of climate quality data record of LST with high stability, regional and global datasets of mean LST for determining relationships with plant health and function, and health and hazards planning.

6.1.2.2Synergistic uses of ATSR/SLSTR data (and other sensors)

LST from the ATSRs is very useful for long-term climate datasets, and for provision of reference LST when integrating data from other sensors. However, many users of LST wish to have observations of LST which resolve the diurnal (24 hour cycle), particularly for obtaining LST at key times of day or night or for estimating differences between maximum and minimum LST. Given the high standard of calibration for most sensors/channels in the series, and the corresponding geophysical accuracy and stability achievable, ATSR and SLSTR can be used as “reference sensors” for merging GEO and LEO datasets of LST (as with SST) to provide global diurnal information and for sub-pixel classification.

It is particularly attractive to merge AATSR with SEVIRI data which is of high quality and thus gives very good merged data for Africa and a large part of Europe.

Efforts to merge LST datasets are on-going within the ESA-funded GlobTemperature project.

Efforts to obtain LSAT from LST are on-going within GlobTemperature but also the EC-funded EU Surface Temperature for All Corners of Earth (EUSTACE) project.

6.1.3 Operational Applications

LSTs affect local meteorology. Being significantly coupled to the atmosphere, LST is highly influential in convection. If uncertainties can be reduced in determining LSAT (which is required for NWP) from LST, given knowledge of the surface state and other meteorological states, such as wind, LST could be exploited in NWP. Both climatology (for a background) and routine observations would be needed. SLSTR LST data processed, for example, through the UK collaborative ground segment or Sentinel-3 systems, based on GlobTemperature algorithms, could meet this NWP requirement.

6.1.4 Requirements on data for Land Surface Temperature

The multitude of applications of LST necessitate a common approach to understanding the broad range of user requirements, since no single dataset or spatio-temporal resolution will meet their different requirements. The current implementation of measures including the adoption of common file formats such as netCDF, and climate and forecasting (CF) convention compliant metadata, is a critical requirement for increased exploitation of LST from AATSR and SLSTR.

Validation and intercomparison information is a crucial requirement for users to better understand the data they are exploiting. Uncertainty information is critical for numerous applications and should be provided with LST data, following a standardised approach to determination of uncertainty budgets which distinguish and quantify the different components of an LST uncertainty budget: random, pseudo-random and systematic. Furthermore, the uncertainties themselves need to be validated to provide further confidence, and a consistent approach to propagation of uncertainties to higher level products. This is critical in applications such as data assimilation, an underlying assumption of which is that the differences between the model and observation are unbiased. Data assimilation operates on a good understanding of observational random uncertainty. However, systematic biases often exist which may have diurnal components; such biases must be accounted for as a matter of course.

A requirement of several applications is a global dataset of LST capturing the diurnal cycle. The full global diurnal cycle cannot be directly obtained from a single LEO / GEO satellite. In the case of LEO satellites, which observe the same surface periodically with intervals of hours or days between consecutive observations, the strong temporal variability of LST means such satellites are limited in their potential to observe the whole diurnal cycle; cloud contamination limits this potential further. In the case of GEO satellites, while the full diurnal cycle can be captured due to their high temporal resolution of observations, they are limited in only being able to view a single region of the Earth's surface. Only by combining both LEO and GEO satellites can a high-spatial resolution, high-temporal resolution LST dataset be generated.

These requirements can be summarised as follows:

- Global gap-filled LST data which resolves the diurnal cycle, with the integration of microwave data to understand the clear-sky bias
- Long and stable climate data record of LST
- LST uncertainties per pixel and on all averaged datasets following standardised approach
- Improved accuracy of LST from cloud-clearing developments and detection of high aerosol loads
- Validation of both LST data and LST uncertainties, and intercomparisons with LST products from different satellite instruments
- Consistent and user-friendly data format for LST data products
- Better understanding of LST vs. LSAT
- Better definitions of land surface temperature in varying biomes
- Possibility of NRT data production of LST

Very high spatial resolution LST (100 m) with good coverage is a requirement for some applications, such as urban heat island mapping. Although alternative sensors are better suited at providing the spatial representation, AATSR and SLSTR data could be exploited to assess the temporal variability for these local applications.

6.1.4.1Product accuracy and availability

AATSR LST data are available from several sources including the ESA and UK CEDA archives. The new GlobTemperature portal is serving AATSR LST data. Typically accuracies are better than 2 K at daytime and 1 K at nighttime.

6.1.5 Gap bridging and gap filling

Land surface temperatures are dynamic quantities and so gap bridging and gap filling require close control of observation times. The SEVIRI instrument on MSG-2 probably provides the most comprehensive gap bridging opportunity being in geostationary orbit although MODIS also offers some potential in its morning slot. Ground-based instruments are not very common and therefore there is a urgency to the development of new validation techniques. Nonetheless the LandSAF/KIT validation stations provide a foundation in LST validation over Africa.

The same considerations apply to gap filling activities except that the nature of LST datasets suggests a merging of low Earth-orbit datasets, e.g. ATSR and MODIS.

6.1.6 Recommendations for future work

1. Full assessment of surface reflectance quality and errors
2. Integrated product development for SLSTR/OLCI
3. Integrated LST products for ATSR/SLSTR merged with geostationary sensors
4. Consistent cloud detection
5. Improved fire products from SLSTR and exploitation in operational systems such as Atmosphere Core Service.
6. Improved geolocation information
7. Improved thermal emissivity over land.
8. Combined studies with models in critical regions of the world: Africa, European droughts; Amazon
9. New methods of using LST and LSWT data with models to define regional climate characteristics
10. Investigations of LST anomalies at small scales: heat islands, biome characterisation; evapotranspiration; soil moisture controls; volcanism; geothermal states; impacts of land cover change

6.2 **Fires**

6.2.1 What are the strategic scientific issues?

The burning of biomass (vegetation and organic soils) is a major component of the Earth system, occurring on all continents apart from Antarctic, and impacting 8 out of 13 identified radiative forcing agents. Biomass burning interacts with Earth's climate and biogeochemical cycles, through impacts on the biosphere (e.g. through changing land cover and alteration of carbon stores), atmosphere (e.g. though the rapid release of numerous chemical and particulate species in large quantities), and cryosphere (e.g. through the deposition of black carbon and the alteration of snow/ice albedo). On average fires burn a worldwide area of around 3.5 million km^2 annually, equivalent to the area of India. However, there are order of magnitude annual variations at the regional scale and strong interranual variability in response to drivers such as as El Niño and other climatic variations. During particular climatic events fire activity can spike dramatically, and the extreme fires that occurred during the 1997-98 El Niño were one of the first times that regional scale terrestrial activity was clearly seen to rapidly and convincingly affect the composition of the global atmosphere. It is now suspected that the major year-on-year changes seen in biomass burning patterns and totals may in fact be responsible for a large part of the interannual variability also seen in atmospheric carbon dioxide (CO2) concentration growth, with some years showing a CO_2 concentration growth twice that of others. These relations have consequences for climate-environment-fire feedbacks, and the accurate representation of carbon cycle and climate processes within Earth system models. Climate change driven shifts in fire regimes have already been noted in higher latitude regions that have long-term fire records, notably Canada, and such changes are suspected also to be occurring elsewhere. These may have further importance for climate-fire-environment feedbacks, since increased GHG releases by fire may in future lead to further climate change and further shifts in fire behaviour. Furthermore, whilst with respect to fire-emitted CO_2, vegetation regrowth may re-absorb much of this over time; permanent deforestation fires and the burning of peatlands that are centuries or millennia old is estimated to be currently responsible for around 15% of the total net annual anthropogenic carbon emission to the atmosphere. This makes such landcover change related emissions the subject of emissions reductions schemes, such as the UN-led Reducing Emissions from Deforestation and Forest Degradation (REDD+). This is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development.

In addition to CO_2, the smoke from vegetation fires contains hundreds of different chemical compounds in lesser amounts, and for certain of these species vegetation fires are amongst the most significant source to the atmosphere. This includes gases like carbon monoxide and particulates like black carbon. Other chemically and/or climatically important atmospheric gases, such as methane and certain volatile organic compounds, also have significant biomass burning sources. Through their ability to release these emissions in vast quantities over relatively short periods of time, vegetation fires are amongst the greatest short-term impactors of global atmospheric composition and regional air quality. Air pollution has become the world's single biggest environmental health risk, linked to around 7 million – or nearly one in eight deaths in 2012 – according to the World Health Organisation (WHO). Though air pollution problems, including those associated with biomass burning, exist in many regions including southern Europe, south-east Asia is now the region suffering the greatest air pollution, much of which is suspected to result from biomass burning (e.g. conduced for land clearance, the maintenance of croplands, and as a result of accidental peat fires in degraded lands). A recent estimate in Nature Climate Change estimated that during strong El Niño years, in which SE Asia typically experiences rainfall reductions and increased fire activity in deforested or degraded lands, there is on average a ~ 2% annual increase (6,800–14,300 persons) in regional adult cardiovascular mortality caused by fine particulate matter (PM2.5) and ozone surface concentrations near fire sources. The Copernicus Atmosphere Service is being set up to monitor and forecast global atmospheric composition in near real time, and downstream services stemming from this development aim to help better identify causal sources of air pollution, map instances of long-range atmospheric transport of pollutants, and forecast and warn of significant pollution events prior to their occurrence so that mitigation measures or policy changes may be enacted.

6.2.2 How can ATSR contribute?

The ATSR World Fire Atlas (WFA) represents the earliest globally consistent record of worldwide vegetation fire activity currently available, commencing some years prior to the December 1999 launch of the first MODIS instrument that currently provides the most widely used active fire record (and the most downloaded EOS MODIS product of all). Whilst the ATSR WFA product only provides information on night-time fires, and purely on their location and timing rather than any other characteristics, it does so in a globally consistent manner than has led to its frequent use in many science studies, and as a component of such widespread fire emissions inventories as the Global Fire Emissions Database (GFED). In contrast to information on burned area, the active fire information from ATSR provides a record of the fire when it was actually burning, with the ability to detect fires far smaller than the nominal 1 km^2 nadir pixel area, down to as small as ~ 0.01% of the pixel. This allows ATSR to detect the type of deforestation fires, where timber from a larger area is cleared, piled and burned, than can burned area products that rely on solar reflective measurements.

Burned area products typically miss such fire events due to their requirement to have the majority of the pixel, and often a number of spatially consecutive pixels, burned. Furthermore, for model-based applications where the fire behaviour is inferred from the timing of the fire and the anticedent meteorological conditions, the ATSR active fire data provides the necessary date and timing information to support this methodology (which is used, for example, by the Canadian Govt to report national carbon emissions totals). In addition to active fire data, burned area maps can be derived from the ATSR solar reflective channels, sometimes supplemented by thermal channel observations. ATSR-2 did not provide continuous solar reflective measurements in all bands at all times, but AATSR did, and so AATSR has been used within the ESA Fire CCI project to develop a global burned area mapping capability extending before the MODIS era.

SLSTR extends the ATSR capability very significantly with respect to the provision of information on fires and biomass burning. In terms of burned area mapping, the wider swath, higher temporal resolution, additional solar reflective channels and increased spatial resolution of SLSTR all lead to a significant improvements over the capability already demonstrated with AATSR. There is also the potential to develop a joint SLSTR-OLCI burned area product, exploiting the even higher spatial resolution offered by OLCI. With respect to active fires the capability of SLSTR is even more improved with respect to that of (A)ATSR. The improvements include, raising of the SLSTR the thermal channel saturation temperatures above those of (A)ATSR, the addition of the two dedicated totally non-saturating "fire" channels that allow radiance measurements over even very high intensity fires, the wider SLSTR swath and higher temporal resolution, and the production of active fire data from both day and nighttime passes, and the production of fire radiative power (FRP) information for the first time. This is a significant enhancement, since fires are typically much more prevalent and much more active by day than by night, and the FRP measures that can now be made have been demonstrated to be directly related to rates of fuel consumption and smoke emission. The SLSTR Active Fire Detection and Fire Characterisation (FRP) product to be generated operationally by ESA is planned to capitalise on these new capabilities.

6.2.2.1Direct uses of ATSR and SLSTR data

ATSR WFA active fire data are used within the global fire emissions database (GFED) to parameterise the fire emissions model. ATSR WFA data are also used within many science studies as a record of the locations and times of biomass burning events (for example to identify aerosols as being associated with fires) and to determine the fire regime of particular regions (e.g. fire seasonality, magnitude of fire season etc).

6.2.2.2 Synergistic uses of ATSR/SLSTR data (and other sensors)

In many science studies, the active fire data from ATSR have been combined with other ATSR-derived products, or data from other sensors, either to provide a more complete picture of fire, or to associate a particular signature seen in the other data or information source with fire. This includes for example, combining WFA data with that of land surface temperature, vegetation cover, aerosols etc, all of which are either drivers of or impacted by fire events. The same is true of combinations of burned area and fire products, raising the possibility of using combined SLSTR and OLCI information to produce world-leading data.

6.2.3 Operational Applications

The primary operational application of the SLSTR FRP data are expected to lie within the Copernicus Atmosphere Service (CAS: https://www.gmes-atmosphere.eu/). The CAS provides continuous data and information on global atmospheric composition through describing the current situation, forecasting the situation a few days ahead, and providing consistent analyses of retrospective data records of recent years. The Service supports many applications in a variety of domains including health, environmental monitoring, renewable energies, meteorology, and climatology. The CAS will make use of the SLSTR Active Fire Detection and Fire Characterisation (FRP) product, generated in near real-time by ESA, within its Global Fire Assimilation System (GFAS). The role of GFAS is to deliver to the CAS' atmospheric models spatially resolved, near real-time estimates of global fire emissions of reactive gases, greenhouse gases and aerosols. Currently the GFAS system runs using MODIS active fire data, which is currently the only polar orbiting EO sensor routinely producing global FRP data despite it not being a formally 'operational' mission. However, with both MODIS instruments now operating for significantly longer than twice their scheduled lifetimes, it is expected that after the first Sentinel-3 launch SLSTR FRP data will become a major component of GFAS and the CAS, eventually replacing MODIS. Furthermore, since fires are highly dynamic phenomena that show strong diurnal variations, but whose thermal signatures are easily hidden by clouds, the addition of the SLSTR data even during the period when MODIS remains operating make these data highly valuable in increasing the temporal coverage. Sentinel-3 is also a formal 'operational' mission, guaranteeing FRP data continuity over the next decades.

In addition to the CAS, based on the widespread use of MODIS active fire data, other potential operational applications for the active fire information stemming from SLSTR include use in national park management, regional fire early warning and response, local and regional air quality modelling, monitoring and dearly warning, and in Africa the real-time detection of grassland fires burning close to electrical supply lines (enabling temporary switch-off to avoid flashover events). Whilst the burned area products are less widely used in operational applications, since they are generally less timely than the active fire information, they are expected to find application in national reporting of greenhouse gas emissions from landscape scale fires and for assessing fire-affected area totals for e.g. national park management and REDD+.

6.2.4 Requirements on data for fires

Fire is an important ecosystem disruptor, with varying return frequencies, resulting in land cover alteration and change, and atmospheric emissions on multiple time scales. Due to the very large spatial and temporal variability seen in fire activity, satellite data provides the most useful means to assess and monitor the phenomena. As such Fire Disturbance has been designated as one of the 50 GCOS Essential Climate Variables (2010), required to support the work of the UNFCCC and the IPCC. All ECVs are technically and economically feasible for systematic observation, and the Fire Disturbance Essential Climate Variable consists of burnt-area maps, active fire (High-Temperature Event; (HTE) locations and times; and Fire Radiative Power (FRP) information. These fire data are used for global change research, estimating at atmospheric emissions, and developing periodic global and regional assessments, and also for planning and operational purposes as outlined above (fire management, local to national) and development of informed policies (national and international, e.g. IPCC). For certain of these applications, for example many of the operational applications, rapid provision of the data to users is a necessity, with the maximum permitted time-lag between the satellite observation and the supply of information to users typically being of the order of a few hours. For certain of the non-time critical applications, requirements with regard to accuracy and the minimisation of false positives become the driving factor.

6.2.5 Product accuracy and availability

Burned area, active fire detection, and FRP datasets together form the fire disturbance ECV, and the separate products can be combined to generate improved information, e.g., mapping of fire affected areas to the fullest extent, including the timing of burning of each affected grid-cell. Estimates of total dry matter fuel consumption (and thus carbon emission) can be estimated from these products. By applying species-specific emissions factors, emission totals for the various trace gases and aerosols can then be calculated.

The current GCOS requirements (GCOS-107) for burned area are: a daily temporal resolution, a spatial resolution of 250 m; stability of 5%, and a maximum omission and commission error of 5%. No current global burned area product derived from satellite EO data meets these requirements in any of the four categories, though 'daily date of detection' is provided in some current products (e.g. MODIS burned area). SLSTR will potentially be able to provide daily data, but the ECV spatial resolution requirements are beyond those capable of being delivered by SLSTR. Stability and accuracy requirements from SLSTR-derived burned area data are not expected to be a significant advance on those of MODIS.

SLSTR has a much greater chance of meeting the current definitions required by active fire detection and FRP data within the ECV, which are less stringent than for burned area (http://gosic.org/content/gcos-terrestrial-ecv-fire-disturbance). Detection of actively burning fires and measurement of Fire Radiative Power (FRP) is often adequately performed at a lower spatial resolution than for burned area (e.g. 1 km), more suited to generation from SLSTR. This is primarily because active fires emit so strongly at MWIR wavelengths that even highly sub-pixel events can be quite easily detected if they have a significant power output (e.g for SLSTR probably ≥ 8 MW). The sensor must have MWIR and LWIR spectral channels with a wide dynamic range to avoid sensor saturation, as SLSTR does, and active fires should ideally be detected from low earth orbit multiple times per day. SLSTR can provide data of an active fire twice per day when both Sentinel-3 satellites are operating simultaneously, though only by combining with other EO data such as MODIS can one of the measurements be located near the peak of the daily fire cycle (typically early afternoon). However, it is the case that typical user-driven target requirements for the active fire information (http://www.fao.org/gtos/doc/ecvs/t13/t13.pdf) are again quite stringent, and not currently met by any sensor (5% maximum error of omission and commission, 250 m spatial resolution for fire detection and 1 km for FRP generation, daily observing cycle). The SLSTR is expected to meet certain of these (1km FRP data, daily observing cycle) but the 5% maximum error of omission and commission is only considered feasible for fires above a certain FRP, for example the ≥ 8 MW threshold mentioned previously, since there will always be many "small" fires that are below the detection limit of any current EO sensor capable of providing daily temporal resolution data.

6.2.6 Gap bridging and gap filling

Prior to the start of the SLSTR mission, MODIS provides similar active fire detection and FRP data, including at a similar overpass time from Terra MODIS. It can therefore be used to extend the FRP record from SLSTR to prior years (in fact back to mid-2000). The crossover period when both MODIS terra and SLSTR are operating, expected to be for the next few years at least, should provide adequate data for cross-comparison and cross-calibration. Use of the ATSR-2 and (A)ATSR nighttime active fire detection record extends these particular type of data back to the mid-1990's, but with some years gap between the end of (A)ATSR and the start of SLSTR. Terra MODIS data, suitably subsampled and/or temporally averaged to mesh with the (A)ATSR sampling strategy, can bridge this gap and allow a consistent time-series to be obtained.

6.2.7 Recommendations for future work

- The ability to extend the SLSTR active fire detection time-series back into the past using (A)ATSR will be highly valuable. Once the (A)ATSR data are in the SLSTR data format (4th reprocessing), the current SLSTR algorithm would require relatively little modification to be able to generate active fire detections from these observations. It will only work at night due to daytime 3.7 micron band saturation over even warm land, and will not provide FRP data over larger fires due to nighttime saturation, but the product should be able to detect many more fire events than are present in the current (A)ATSR World Fire Atlas (WFA). Furthermore, having a single consistent fire dataset, delivered with very similar algorithm, will enable the detection of trends in fire regimes due to shifts in climate and/or other environmental or human factors. Analysis of the current WFA alone has not yet been able to generate a convincing regional signal showing a climate-related fire regime shift, though the suspicion is that such shifts maybe underway.

- A further piece of work in relation to fire would be enhancement of the SLSTR cloud classification scheme over land, which all terrestrial products in addition to fire would benefit from. It would be important to discriminate smoke from clouds and not to have tests that incorrectly flag fires (e.g. due to their large IR BT differences) as cloud.

- Generation of a burned area product from SLSTR should also be adopted, and the active fires will very likely act as a "seed" classification point for any such algorithm, as is the case with the MODIS burned area algorithm. It seems likely that the ESA Fire CCI will take on this latter task.

6.3 Lake Surface Water Temperature

6.3.1 What are the strategic scientific issues?

The ARC Lake project has demonstrated that lake climatological and time series information is able to be determined from ATSR/SLSTR for the majority of large (>500 km2) lakes globally, and for several hundred further smaller lakes (down to 50 km2). However, the quality of the information for smaller lakes is not yet validated. Large lake information has been adopted already as the background climatology in the OSTIA system i.e., the surface temperatures provided revert to ARC Lake climatological values if other information is not available.

The strategic scientific issue for lake remote sensing from a meteorological (NWP) perspective is to establish reliable sustained lake observations, backed up by well validated climatologies, suitable to inform weather forecasting and constrain lake models. As noted in setting up the ARC Lake project, SST and/or generic land ST techniques are significantly sub-optimal for lake products.

The strategic scientific issue for lake remote sensing from a climate perspective is to establish the change in lake temperatures and ice-covered periods (ice phenology) over the long-run (>20 years with stability at level 10 mK/year). This is in order to (1) act as a sensitive indicator of regional climate change and variability, that integrates influences of air temperature and radiative environment, (2) provide data for climate model testing (as models move to higher resolution and more often explicitly represent inland water bodies).

The strategic scientific issue for lake remote sensing from an ecological/geographical perspective is to link lake surface water temperature and ice phenology data to their ecological impact (and feedbacks) in the context of their catchments. This requires linking to other forms of remotely sensed lake data (radar ice coverage, altimetric lake levels, chlorophyll concentrations, turbidity estimates, catchment precipitation). The aim should be to provide lake data of a quality sufficient to support the scientific and management applications of the communities that interact with each given lake, on a global, accessible basis.

6.3.2 How can ATSR contribute?

6.3.2.1Direct uses of ATSR and SLSTR data

Direct uses of ATSR and SLSTR data include:

- Accurate, stable measurement of lake surface water temperature.

- Inference of ice phenology (ice on and off dates).

6.3.2.2 Synergistic uses of ATSR/SLSTR data (and other sensors)

Given the high standard of calibration for most sensors/channels in the series, and the corresponding geophysical accuracy and stability achievable, ATSR and SLSTR can be used as “reference sensors” for the satellite constellation for lake temperatures, as with SST.

Integrated views of lakes for management and environmental science applications require joint use with radar ice coverage, altimetric lake levels, colour-based chlorophyll concentrations (e.g., MERIS, OLCI), and colour-based turbidity estimates.

6.3.3 Operational Applications

LSWTs over large lakes affect local meteorology significantly (lake snow effects, etc) and are required for NWP. Both a climatology (for a background) and routine observations are needed. SLSTR LSWT data processed through the UK collaborative ground segment and based on ARC-lake techniques could meet this NWP requirement.

6.3.4 Requirements on data for lakes

6.3.4.1 Product accuracy and availability

- LSWT accuracy: propose target of 0.3 K for all lakes with areas >50 km^2
- LSWT stability: 10 mK/yr, globally
- LSWT consistent with available climatology need to be available in at worst short-delay mode, and possibly NRT.

6.3.5 Gap bridging and gap filling

Lake surface water temperature is an excellent new product from the ATSRs. New projects need to develop methodologies also for SLSTR. Gap bridging and gap filling require close working to identify and work through new routes that might become available.

6.3.6 Recommendations for future work

Improved auxiliary information on lake extent needs to be developed for variable lakes. Two classes of these exist: lakes undergoing long-term changes, and lakes that are naturally seasonal and/or intermittent. Landcover datasets describe these with only 5 year resolution at present. ATSR, SLSTR, MERIS, OLCI, SAR, MODIS, LandSat and other data would ideally be combined to determine the time evolution of variable lakes at (at least) monthly resolution.

Validation of ATSR/SLSTR-based LSWTs lags the production of datasets. This is in part because there is no single source of validation data but multiple sources which are laborious to track down and obtain (quite apart from some data holders wishing to retain data). To establish securely the credibility of ATSR/SLSTR LSWTs, much broader validation will be required.

LSWTs from ATSR/SLSTR need to be:

(1) combined/blended with LSWT from other missions (Metop-A & B, MODIS), to give long, climate-relevant, harmonised time series

(2) assembled with different sorts of lake data (level, turbidity, chlorophyll, ice cover) in accessible forms to stimulate exploitation for science and management

Key points:

1. Operational LSWT production for assimilation into NWP
2. Serving of data on domain-specific portals e.g. LSWT, and user encouragement
3. New methods of using LST and LSWT data with models to define regional climate characteristics

6.4 Land Surface Reflectance

Land surface reflectance is required for deriving a wide range of biophysical variables relevant to modelling of carbon, energy and hydrological cycles. The goal of the addition of optical channels to the ATSR series was to extend the role of the instrument to land surface climatology and to allow determination of green fractional cover to assist in estimation of land surface temperature. As visible calibration, geolocation and ability to correct for atmospheric scattering have improved, the potential of the instrument to contribute climate relevant datasets from the optical channels has increased, but to date been little exploited.

6.4.1 What are the strategic scientific issues?

Land surface reflectance, an estimate of energy received at surface at each divided by downwelling flux, and requires correcting for the effects of atmospheric absorption and scattering. Reflectance is most directly related to surface albedo. Albedo is one of the primary drivers controlling planetary radiative energy budget, but requires directional and spectral integration to allow it to be related directly to total solar flux. Radiation studies would also benefit from the estimation of downwelling radiation at the surface, which theoretically could be derived from ATSR and SLSTR data.

Surface reflectance is also the primary starting point for estimates of land cover type, vegetation fractional cover, leaf area index (LAI), and fraction of absorbed photosynthetically active radiation (fAPAR), required for modelling vegetation productivity, and evapotranspiration. The temporal sampling required for many of these applications necessitates the use of coarse spatial data. In addition improved understanding of vegetation phenology is needed to improve modelling of climate change impacts and feedbacks, where more simple indices are frequently used, but require normalization at least for solar/view geometry to robustly distinguish surface temporal patterns.

6.4.2 How can ATSR contribute?

6.4.2.1Direct uses of ATSR and SLSTR data

The (A)ATSR series and successor SLSTR are capable of providing a long-term record of highly calibrated global satellite data for land surface. The dual-view capability has been demonstrated to allow robust estimation of aerosol over the land surface, which are typically the largest uncertainties in estimating surface reflectance from satellite radiances. Research has demonstrated methods in theory for estimation of LAI, FAPAR, vegetation fractional cover and vegetation indices. The most common alternatives are products from the AVHRR, MODIS, SPOT-VGT and MERIS, sensors but all demonstrate some inconsistency in temporal patterns, and temporal sampling can be improved by use of multiple instruments. The main limitation of AATSR is limited temporal sampling compared with comparable instruments, but this will no longer be the case with SLSTR on Sentinel-3

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6.4.2.2Synergistic uses of ATSR/SLSTR data (and other sensors)

Under ESA funding a Synergy product has been developed for SLSTR and OLCI on Sentinel-3, giving both atmospheric aerosol an land surface reflectance at all OLCI and SLSTR wavebands. A prototype has been developed within the BEAM framework using AATSR and MERIS. There is also potential to improve land surface temperature determination by combined SLSTR and OLCI, for example by improving surface emissivity and moisture estimates. This has been initially explored within the ESA SEN4LST project.

6.4.3 Operational Applications

Main operational applications of such products are for use as driving data for land surface modelling at regional to global scales, analysis of vegetation patterns and cover type, surface radiation budget calculations and operational use of land cover/land change data sets.. Within ESA GlobCarbon project, both AATSR and SPOT-VGT were used to produce time series of LAI at 1km. Within the ESA GlobAlbedo project, AATSR was envisaged to be used along with MERIS and SPOT-VGT, but difficulties in geolocation at project time prohibited use of the ATSR data. This is much less likely to be a difficulty for SLSTR data.

6.4.4 Requirements on data for land surface reflectance

6.4.4.1 Product accuracy and availability

Currently the ESA Grid Processing on Demand offers a prototype demonstration product to produce surface reflectance at 1km resolution. In addition, the Synergy BEAM tool produces surface reflectance for combined AATSR and MERIS data. Accuracy has not been defined yet for either product. For Sentinel-3 there will be a surface reflectance and aerosol product through OLCI/SLSTR synergy, and also resampling to SPOT-VGT wavelengths to allow interchangeability for this user community, for example in deriving products through GIO global Land Component.

6.4.4.2 Gap bridging and gap filling

Suitable datasets of surface parameters for gap filling between AATSR and SLSTR are potentially available from MODIS, SPOT-VGT and PROBA-V sensors.

6.4.5 Recommendations for future work

(i) The existing archive of ATSR-2 & AATSR has potential to offer an independent and stable time series of surface reflectance and associated biophysical variables (LAI, fAPAR). Integration of surface reflectance from (A)ATSR within the framework of the GlobAlbedo also has potential to extend this record temporally, and allow greater temporal sampling.

- Very good calibration of visible channels and atmospheric correction could be a particular signature of the AATSR data.
- Further work on algorithms for biophysical variables such as fAPAR would be valuable.

(ii) Use of SLSTR dual view has been integrated into the Sentinel-3 standard Synergy product, producing estimate of atmospheric aerosol and surface reflectance for all SLSTR and OLCU solar reflective wavebands, and associated uncertainty. There is an urgent need to validate these products post launch, and feedback improvements to algorithm development to enable uptake of validated products by the user community at the earliest date.

(iii) Surface reflectance from SLSTR, and in combination with OLCI, offers great potential for land surface biophysical variables (albedo, LAI, fAPAR, leaf water and chlorophyll) at much greater temporal resolution than the ATSR series, and at finer spatial and spectral resolution. Further research is required to develop and validate such product

(iv) Investigate the efficacy of producing estimates of downwelling flux at the surface from ATSR and SLSTR data.

7 THE ATMOSPHERE

The ATSRs and SLSTR provide a quite significant amount of scientific information on the atmosphere, including cloud parameters, aerosol parameters, water vapour and, in a relatively new development, polar wind motion vectors. In the first ATSR-1, although dual-view, a lack of visible channels prevented good retrievals of aerosols themselves. Nonetheless, information on stratospheric and tropospheric aerosol was clearly present in the difference between forward and nadir views. Subsequently, users of ATSR-2 and AATSR made increasingly full use of new visible channels to derive aerosol and cloud properties. The SLSTR provides further improvements including additional channels designed specifically to enhance cloud retrievals and sensitivity, particularly for cirrus clouds.

Although the particle retrievals are the main aspects for the ATSR mission, water vapour information is present in the thermal region of the spectrum and thus affects the channels from which surface temperatures can be derived. In the most advanced algorithms, input water vapour fields can be produced as back-up to analysed versions through the modification of, e.g., ECMWF water vapour data in optimal estimation-type algorithms. There also new dedicated algorithms for water vapour retrieval over the ocean.

7.1 What are the strategic scientific issues?

The strategic scientific issues, for which long-term measurements are also important as discussed in the climate section, include:

1. Aerosol and cloud lifecycles
2. Radiative forcing of aerosols and clouds
3. Aerosol and clouds as mediators of chemistry
4. Responses of aerosols and clouds to changing climate and environmental factors
5. Aerosol pollution in cities and in dust outflows.
6. Water vapour variations at spatial resolutions commensurate with nowcasting model scales.

These high level science areas are a coverall for a whole series of strategic challenges with some key science imperatives to understand:

- Long time series of aerosol change (key parameters)

- Use of ATSR aerosol data for climatological air quality studies
- Exploration of aerosol evolution at low concentrations (background aerosol)
- Aerosol radiative forcing
- Aerosol mediation of atmospheric chemistry
- Volcanic aerosol and cloud interactions
- Arctic cloud and aerosol interactions
- Cloud sensitivity to climate
- Water vapour contributions to the global hydrological cycle and its trends.

A key question in aerosol-cloud interactions is what are the effects of biomass burning on cloud properties? Biomass burning aerosols can have an indirect or semi direct effect on clouds. The effect on the Earth's radiation budget is significant but the magnitude is unknown. The effect of these aerosols on clouds is variable and depends on the location of the aerosol (above/below/within) the cloud. Typically, over the ocean, aerosol is at higher altitudes than over the land and indeed for the ocean, aerosol can often be viewed over clouds. Many regions of the world have regular seasonal biomass burning events. It is critical to have the capability to study these events over a decadal time scale and this is where ATSR and other sensors can come in.

Having characterised the aerosols, it could then be possible to examine also in a biomass burning plume the effects on atmospheric chemistry and the fraction of aerosol which is due to secondary organic aerosol. At the same time, the presence of clouds and water droplets may remove key species from the chemistry such as formic acid, modifying the acidity of the plume. Thus the strategic questions are often linked, from the life cycle issues where the interactions of aerosols and clouds may initiate particle growth or accelerate them, to the influence of fire on atmospheric chemistry.

Another interesting question for aerosols is around their formation in distinct events such as degassing volcanoes, where gases are emitted into the troposphere where the resulting aerosol formation can have a longer timescale.

In terms of clouds, the radiative impact is important to understand and can change sign, which makes the cloud feedbacks a key parameter. In many general circulation models, the outputs of model runs under the same scenarios are quite diverse. So, for example, how do high clouds respond to a warming climate? A dominant contributor to the positive cloud feedback in models is the increase in height of deep convective outflows, accorded the fixed anvil temperature mechanism. According to this mechanism the outflow level from deep convective systems is determined in steady state by the highest point at which water vapour cools the atmosphere through infra-red emission. This occurs at a particular water vapour partial pressure, therefore at a similar temperature (higher altitude) as the climate warms. A positive feedback results because since the cloud top temperature does not keep pace with that of the troposphere, its emission to space does not increase at the rate expected for no feedback effect. Observational records have not yet provided reliable data records but ATSR data has the potential to do so.

Very good information on water vapour itself is important. Water in the atmosphere is a key input to weather forecasting models; it is a radiatively active gas and humidity has a profound influence on particle formation. The trend in water vapour is a key challenge in observations of natural greenhouse gases. Many satellite retrieval systems use ancillary water vapour as inputs to data processing systems.

7.2 **How can ATSR contribute?**

The AATSR instruments have excellent dual-view capability, although for aerosol retrievals in particular there are challenges due to the different sizes of field-of-view of the forward and nadir views, and the fact that land is heterogeneous over the scale of the ATSR pixels. Over the oceans where the algorithm performs better, the AATSR data for aerosols are very good. These capabilities need to be extended into the SLSTR timeframe where the observations from the backward view of SLSTR will have to be tied to the forward view observations of the first there ATSRs. Aerosol data over land is likely to grow in importance particularly for applications.

The determination of high resolution water vapour, consistently with cloud information, would result in a useful 1 km product with sensitivity in the lower atmosphere. If suitable retrieval diagnostics were included then this could be a leading development, combining water vapour information with excellent ATSR calibration characteristics. Such a product should be consistent with the surface temperature data.

7.2.1 Direct uses of ATSR and SLSTR data

The direct use of the ATSR instruments is in studying long-term aerosol changes as described in the climate section, and in providing data with which the height, ideally type, and effective radius can be brought to bear at the same time as cloud data on cloud top height and optical depth. This requires quite a lot of further work particularly in the uncertain areas where the aerosol algorithm may flag a pixel as cloudy but the cloud algorithm may not, and vice versa.

The swath width of AATSR makes it a little more limited for process-style observations but this is less the case for SLSTR. Here the SLSTR data will provide a much wider coverage of aerosols, and this in itself will be of benefit.

The AATSR datasets are particularly suited to studying strong aerosol events with purity of type. Fire events, dust events and volcanoes all provide signature events which matter in terms of impact on economy and peoples' health.

The AATSR aerosol data is particularly good for regional type studies where the statistics of the data are sufficiently large that good coverage is obtained. Nonetheless there has also been some concern that satellite sensors do not sample the full distribution of aerosols and there is still a challenge to understand the sensitivity of the instrument to low altitude aerosol.

Direct use of ATSR cloud data is in its infancy as work is ongoing to refine retrieval algorithms. However ATSR-type data have been used to study properties of cirrus clouds and to study cloudiness above ship tracks. This is even more true for water vapour where retrieval techniques are just being developed.

7.2.2 Synergistic uses of ATSR/SLSTR data (and other sensors)

Synergistic uses of aerosol data are developing. A key aspect is to analyse more than one satellite dataset at the same time, ideally but not necessarily with the same algorithm. This is to give confidence in analytical work since the temporal variations of aerosols are large and often much larger than the signals one is looking for. A favourite combination for AATSR is MODIS because of the similar performance of the two sensors and their algorithms. However this is only suitable for slowly varying fields. An alternative has been to explore synergistic retrievals utilising both AATSR and MERIS on the same platform; spatial resolutions of the order of 4 km have reduced geolocation issues.

Another possibility is AVHRR but this is less secure because the wavebands, and calibration, of the AVHRR are not as good for aerosol retrieval and the calibration of the optical channels is non-optimal (but has improved rapidly over the last year).

A third approach is to combine spectral information with the dual-view capabilities of ATSR instruments and is appropriate for aerosol retrievals. Aerosol data sets have been successfully produced through combinations of SCIAMACHY and ATSR using this approach

Intriguingly, work on synergy of the so-called passive sensors with the active Cloud-Aerosol Lidar with Orthogonal Polarization (Caliop) Cloudsat sensor is less strong. The advantage of the latter system is that it provides an indication of scattering throughout the aerosol and cloud layer.

For clouds, there has been some work examining the use of ATSR and MERIS in synergy. The geolocation accuracy of the first three ATSRs does not lend itself to detailed cloud studies. However, improvements for SLSTR have been specified so that co-registration with the MERIS follow-on instrument, OLCI, on Sentinel 3 should be much more precise. The prospects for synergistic work will improve considerably. For water vapour, where the key atmospheric fields may not vary rapidly in the spatial domain, combination of SLSTR and OLCI data would be challenging but a real opportunity to characterise near-surface humidity.

7.3 Operational Applications

The ATSR data sets for aerosol have been used in pre-operational Copernicus services (MACC). The needs for this service have led to considerable requests for an aerosol product over land and sea from Sentinel-3. This has led to the implementation of a synergistic retrieval approach using both SLSTR and OLCI as described above. If successful, it is clear that the Copernicus Atmosphere Service will use the data.

Data for water vapour, particularly synergy products, could be very useful for weather forecasting, if developed over land.

7.4 Requirements on data for the atmosphere

The requirements on data for the atmosphere essentially concern aerosol and clouds on the one hand, and water vapour on the other.

7.4.1 Product accuracy and availability

ATSR aerosol and clouds products are available through the Global Retrieval of ATSR Cloud Parameters and Evaluation (GRAPE) website but most recently through the aerosol and cloud CCI datasets. Key parameters are aerosol optical depth at 550nm and other wavelengths, fine mode fraction, dust fraction and aerosol absorption optical depth. Effective radius is also obtainable for aerosol and cloud. Typical accuracies are of the order of 20-30% at the 10 km grid scale or 1 degree scale.

Data sets have availability through NEODC (CEDA-EO) and the ESA CCI projects. Nonetheless it is also true that users would benefit from better signposting and demonstrators of how to exploit the data. It is expected that this phase of the AEP will see this come to fruition.

For water vapour retrievals, products are still in development and it is not yet appropriate to make them available to the community except for validation and intercomparisons.

7.4.2 Gap bridging and gap filling

The MODIS instrument on Terra is the preferred instrument for gap filling for aerosols and clouds. Datasets are available for this purpose, although not analysed with a consistent algorithm and approach to ATSR. The alternative is AVHRR but it does not have quite the same wavebands or calibration accuracy. As the gap to SLSTR grows, however, the strategy may ultimately be determined by which instruments are operational through the gap.

For gap bridging, the ground-based Aeronet network of sensors provides linking observations of good fidelity, allowing both AATSR and SLSTR to be validated to the same standards. If the results are good, then this would allow consistent use of the two data sets, even with a gap in the time series. It is less clear what would be the case for cloud retrievals. For water vapour retrievals, comparisons with the GRUAN network or other networks of global radiosondes should provide good bridging between the sensors.

7.5 Recommendations for future work

1. Full investigation of forwards to backwards view impacts on aerosols and clouds
2. Consistent cloud detection and handling of mixed aerosol/cloud pixels.
3. Accuracy of ATSR aerosol at low concentrations
4. Emphasis on aerosol types: black carbon, dust, volcanic ash
5. More demonstrations of the use of ATSR cloud information
6. Geophysical validation and testing of radiance consistency for water vapour data alongside surface temperature data for both AATSR and SLSTR.
7. Development of polar wind vectors from SLSTR (ideally multiple sensors)

8 THE CRYOSPHERE

The cryosphere represents a multi-faceted domain, unified through the influences of solid water, but with many different forms evolving at different rates and each with particular influences or impacts from global change. We can distinguish permanent ice sheets, snow, sea ice, freshwater ice, glaciers, and permafrost for which the ATSR series of instruments can provide surface observations, albeit at 1 km spatial resolution.

8.1 What are the strategic scientific issues?

Undoubtedly the most significant issues in cryosphere science from satellites have become strongly connected to climate change. Dramatic changes in the Arctic sea ice are one reason, but equally there are many others such as changes in the permanent ice sheets of Greenland and Antarctica, strong decreases in Northern hemisphere snow cover and glacier retreat. These can be quantified through surface temperature, ice and snow cover, estimates of mass change of ice and freshwater fluxes. The cryosphere is dynamic, revealing short-term responses with implications for resources, exploration and potential tipping points for circulations, greenhouse gas release and land cover. Long-term ice decreases are a strong contribution to sea level rise. The complex Arctic world requires observations of all the cryosphere components and provides a compelling case study of significant scientific and societal importance.

The influence of the cryosphere on atmospheric and oceanic circulation naturally also implies an impact in numerical weather prediction, particularly for the northern hemisphere. Improved surface observations in the poles could play important roles in improving regional and hemispheric weather forecasts.

As polar regions grow in economic importance, improved local forecasting using satellite data will become more urgent. There is an important interaction in cryosphere observations between evolving ice/snow conditions and the ability to deliver accurate surface data from satellite. The two are related through the assessment of biome and vegetation conditions and their use in the retrieval process. Errors will increase uncertainties in polar records of surface temperature and albedo for example; these are key parameters in the polar and high mountain regions.

8.2 How can ATSR contribute?

8.2.1 Direct uses of ATSR and SLSTR data

In cryosphere areas, ATSR can contribute in its traditional areas of strength which include surface temperatures and surface albedo of ice/snow regions. These provide very pertinent datasets for radiation characterisation in climate and NWP models. They can also show long-term trends. A pre-requisite is very good cloud detection over white surfaces and these situations should be tested specifically within projects testing ATSR cloud detection algorithms. The ability to assign surfaces to “biomes” or other markers of condition is important for most current ATSR algorithms. Therefore, snow flagging and hence maps of snow extent are useful products both for consistency within the project and for external users.

Development of high level products such as snow grain size could be possible but needs further research (see next section).

8.2.2 Synergistic uses of ATSR/SLSTR data (and other sensors)

There is a great benefit to synergistic uses of ATSR and SLSTR data. The AATSR data have already been combined with MERIS for snow extent in current studies. Surface albedo can also benefit from the increased wavelength coverage when combined synergistically with MERIS. Similarly experiments with snow parameters such as snow grain size will improve with synergy (providing the time displacement between the observations is smaller than the timescales for snow pack change). The prospects for progress with Sentinel-3 are very good because of the improved geolocation and the improved channels which could improve cloud/snow/ice discrimination.

A second value to synergy is better spatial and time resolution of snow extent. The ATSR data are clearly limited by swath width. This will improve considerably with SLSTR but nonetheless merging and cross-referencing of a number of sensors will help, such as MODIS and AVHRR with AATSR; VIIRS and AVHRR with SLSTR.

A very difficult synergy but one which would bear some investigation is the synergy between ATSR/SLSTR and microwave instruments for cryosphere temperature. The differing spatial scales are challenging (microwave data are lower spatial resolution compared to the ATSRs) but the microwave can provide surface temperature data even in cloudy conditions, allowing tests of the clear sky-cloudy bias and verification of ATSR surface temperatures.

8.3 Operational Applications

The economic importance of understanding the cryosphere and the need for good local weather forecasting provides a focus for cryosphere services from tourism to oil and gas to ecological services and environment agencies. There are a number of public and industry information services including the National Snow and Ice Data Center (NSIDC), the GlobSnow project, and the PolarView service. Key parameters are snow extent, including fractional snow cover. Surface temperatures are also expected to have an impact when released.

8.4 Requirements on data for the cryosphere

8.4.1 Product accuracy and availability

Snow extent and fractional snow cover are available through the GlobSnow project. Performances are not well defined but will receive attention in 2015. The aim is for fractional snow cover estimates that are accurate to 25% or better. Products are available.

Surface temperature over snow and ice should be determined to better than 1 K but quantitative validation of the data is difficult to achieve. There are no specific products available but surface temperatures over snow and ice can be found in the Land Surface Temperature products on the GlobTemperature web-site and on NEODC. It is not clear what are the best cloud and snow flags and hence there is a lack of consistency between different products.

Snow parameters are more difficult to obtain and require further research.

8.4.2 Gap bridging and gap filling

Gap bridging and gap filling represent particular difficulties for the cryosphere area as it is far from static in terms of surface conditioning, e.g. variability of snow, ice thickness, sea ice cover etc. The best means of gap filling in snow extent and fractional snow cover is probably to tie to MODIS which has well developed snow and ice products. For surface temperature, it is possible that MODIS data could be used but there are considerable differences between MODIS and AATSR data which need to be explored further before a conclusion can be drawn for SLSTR.

8.5 Recommendations for future work

The mission drivers for the ATSRs in the cryosphere domain are improved quality of observations of the poles and large snow fields. Key parameters are snow extent, fractional snow cover and surface temperature. Other snow parameters need further theoretical and case study work. The key recommendations are:

1. Improved discrimination of domains: cloud, sea ice, sea, land, land ice, snow. Sharing of flagging results and consistent use of snow and ice flags.
2. Further work on validation of polar datasets including new observations for SLSTR
3. Further assessment of the uncertainties of surface parameters in cryosphere, including temperature.
4. Derivation of snow extent data and fractional cover from SLSTR/OLCI. Use of consistent snow and ice flags with surface temperature and surface albedo products.
5. Exploitation of snow extent data in conjunction with temperature and albedo products
6. Further assessment of the derivation of snow parameters from SLSTR and other Sentinel-3 instruments.

9 OPERATIONAL APPLICATIONS

9.1 Introduction

This section describes operational services which have previously used ATSR data and are likely to use SLSTR data in the future. Such services are briefly described in each of Chapters 4 to 8. The aim of this chapter is to provide an overview of services so as to provide a high level framework for demonstrating the impact of what was previously termed “research data”. Key highlighted services include the GODAE High Resolution SST Pilot Project (GHRSST-PP). This highly successful, service developed the basis for an operational service for SST (although for AATSR it was based on a pre-operational satellite, Envisat) and highlighted the impact that ATSR-type instruments could have. The influence of ATSR-type instruments on weather forecasting services has also grown as a result and now includes developmental studies on other parameters. Finally, we highlight the newly operational Copernicus services which will use Sentinel-3 data: ocean, atmosphere and climate.

9.2 Operational applications and the OSTIA SST analysis

9.2.1 GHRSST-PP and Medspiration

The operational use of ATSR data took a major step forward as a result of the ESA-funded Medspiration project, which 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 developed and introduced a new format, Level 2P (L2P), 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 ATSR SSES are particularly sophisticated and effective on account of the fact that 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.

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

GHRSST-PP continues as the Group for High Resolution SST (GHRSST).

9.2.2 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 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

It is fully expected that OSTIA will incorporate SLSTR data once data flows have been put into place.

9.3 The weather forecasting services

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 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 acquired operational status. The OSTIA methodology has proved to be successful and therefore its use extends to this day. The utilisation of SLSTR SST data in synergy with other sensors remains a prime objective.

The success of the SST data and the availability of AATSR lake surface water temperature data for large lakes have led to the incorporation also of lakes, via OSTIA. So far, however, there has been little use of sea ice detections from AATSR. Increased development and weight on land surface models in weather forecasting schemes has led to an interest in land surface temperatures. Projects are ongoing to look at their use in weather forecasting. Finally, new products such as polar wind vectors are of high interest.

9.4 The EU Copernicus programme

Copernicus consists of a complex set of systems which collect data from multiple sources: earth observation satellites and in situ sensors such as ground stations, airborne and sea-borne sensors. It processes these data and provides users with reliable and up-to-date information through a set of services related to environmental and security issues. The overarching objective is to serve environmental and security-related information readily available to the people who need it, particularly government, policy makers and business.

Further details are obtainable from http://www.copernicus.eu.

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

1. The space observation segment, initially funded by ESA and consisting of a series of Sentinel satellites (of which Sentinel-3 and SLSTR is discussed in this document)

2. The Core Service Elements which provide the services and which have just become operational

There are six Copernicus Service areas: land, marine, atmosphere, climate change, emergency management and security.

Of these, the ocean, atmosphere and climate services are most relevant to SLSTR and the earlier ATSRs. The ocean service will make use of SLSTR data for OSTIA-type analyses and for assimilation into ocean forecasting models. The climate service should make use of the key long-term climate data sets identified in this AEP. The atmosphere service is particularly interested in aerosol and fire data. The data quality and timeliness of SLSTR data will be important attributes in enabling SLSTR to contribute fully to the appropriate services.

In the Sentinel-3 era, there exists the exciting possibility for SLSTR data to contribute much more strongly to land services, particularly through synergistic products, including the Copernicus Land monitoring service.

9.5 Further remarks concerning ATSR and operational applications

The strong growth in operational utilisation of ATSR-type data is a new but very welcome development for AATSR and SLSTR. It is now an arena in which ATSR can contribute in many ways to different services through a range of synergistic techniques and products. One example is GlobTemperature which is finding that serving LST data in an accessible way tends to yield significant user uptake. Data access is a key for many users. Other examples include permafrost and urban services.

There is no doubt that the growth in services from the ATSR-type instruments will be accelerated by SLSTR if the instrument works well and data are of good quality. It will be a challenge to exploit all the possible opportunities for the contributions arising from new long-term data sets. It will also be extremely useful and rewarding to dedicate more time to interacting with main services and their users.

9.6 Recommendations for further work

The most important next step is to build on the success of GHRSST-PP and OSTIA for other products. A strategy needs to be devised, working with ESA, Eumetsat and the EC, to make good connections between the SLSTR experts (for example in the Sentinel-3 mission performance centre), the academic experts and the users. Such a system would support the service providers with information from a sensor-specific operational group.

The recommendations for future work include:

1. Greater efforts at user engagement in conjunction with the SLSTR mission experts.
2. Promotion of SLSTR data to other meteorological services for similar applications.
3. Building of expert support mechanisms for the new government and business users.
4. Support for an international GHRSST-type project for LST, polar temperature, aerosols, and snow.
5. Support for development of polar winds for meteorological agencies.

10 UNDERPINNING ACTIVITIES

10.1 Overview

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

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

The following sections will consider each of these in turn.

10.2 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 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 ATSR programme.

In the future, this validation activity will become ever more important. The use of SLSTR 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" SLSTR datasets in a manner analogous to that for the ATSR instruments.

10.3 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 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 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" implementation of successful algorithms. The design lifetimes of the SLSTR instruments means that production of offline products could only be undertaken at major data centres.

10.4 Data delivery

Ready availability of the ATSR data products is essential if the data are to be used by scientists and operational users. SLSTR data will 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 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.

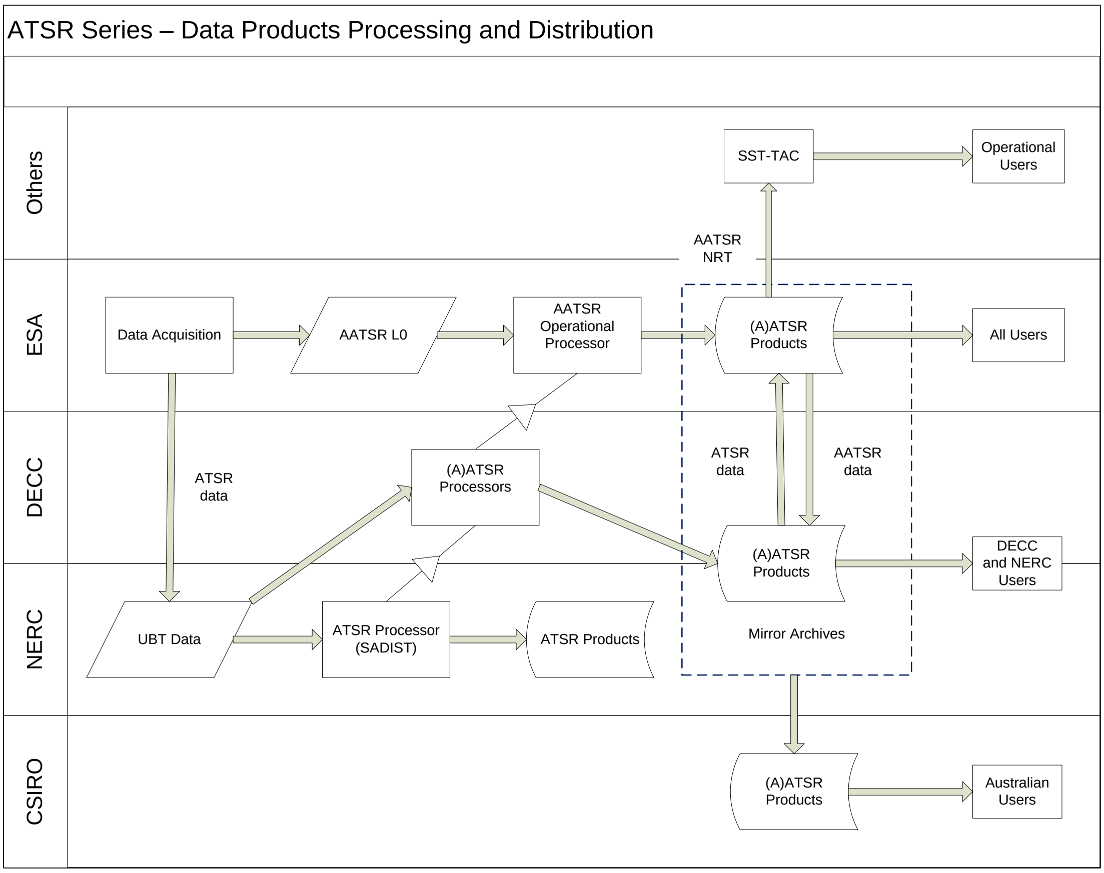

Figure 5-1: ATSR data flows

One of the aspects that will be the key to user exploitation will be the interface to the archive for ATSR and SLSTR data. 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.

10.5 Data continuity

An important objective of 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 ATSR sensors thereby provide an 21 year dataset (through April 2012) 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 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 the SLSTR as an SST measuring instrument on Sentinel-3. It is 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 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.

10.6 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 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 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, and following the failure of Envisat in April 2012, there will be a gap between AATSR and SLSTR of at least four years. 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 QWGs maintains oversight of calibration, validation and data homogeneity, and algorithm changes. All changes to the existing ATSR data products that takes into account validation issues and algorithm improvements are implanted in a controlled manner so that the integrity of the ATSR archive is preserved. The Mission Performance Framework for SLSTR needs to work in a similar manner with a connection to continuing ATSR activities.

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. In the future it would be ideal to integrate the QWG and research activities, for example into new algorithms, in a thematic platform of some type.

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. Likewise the SLSSTR data will be a key priority for incorporation into national and global analyses.

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 Sentinel 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. This will be important going forward with SLSTR.

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 GHRSST 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 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 cross-calibration 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 ATSR websites and are published in peer-reviewed scientific papers. The routes for climate quality calibration need to be established firmly for SLSTR.

(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 10.00 to 1030 a.m. These data can be used to monitor seasonal changes and long-term inter-annual changes. 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. The same is the case for SLSTR.

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

1. *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.

2. *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. 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.

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

   This has had to be addressed by identifying gap filling activities that can extend from the nominal start of the Sentinel-3 mission backwards in time until the failure of Envisat in April 2012.

4. *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 of all the ATSR-type instruments.

5. *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.

6. *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.

7. *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.

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

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

   NERC 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; indeed these radiometer observations are a priority for the SLSTR era. 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.

10. *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.

10.7 Further remarks concerning underpinning activities

The underpinning activities are essential activities to monitor and improve ATSR data product quality. At the core of this effort is the 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.

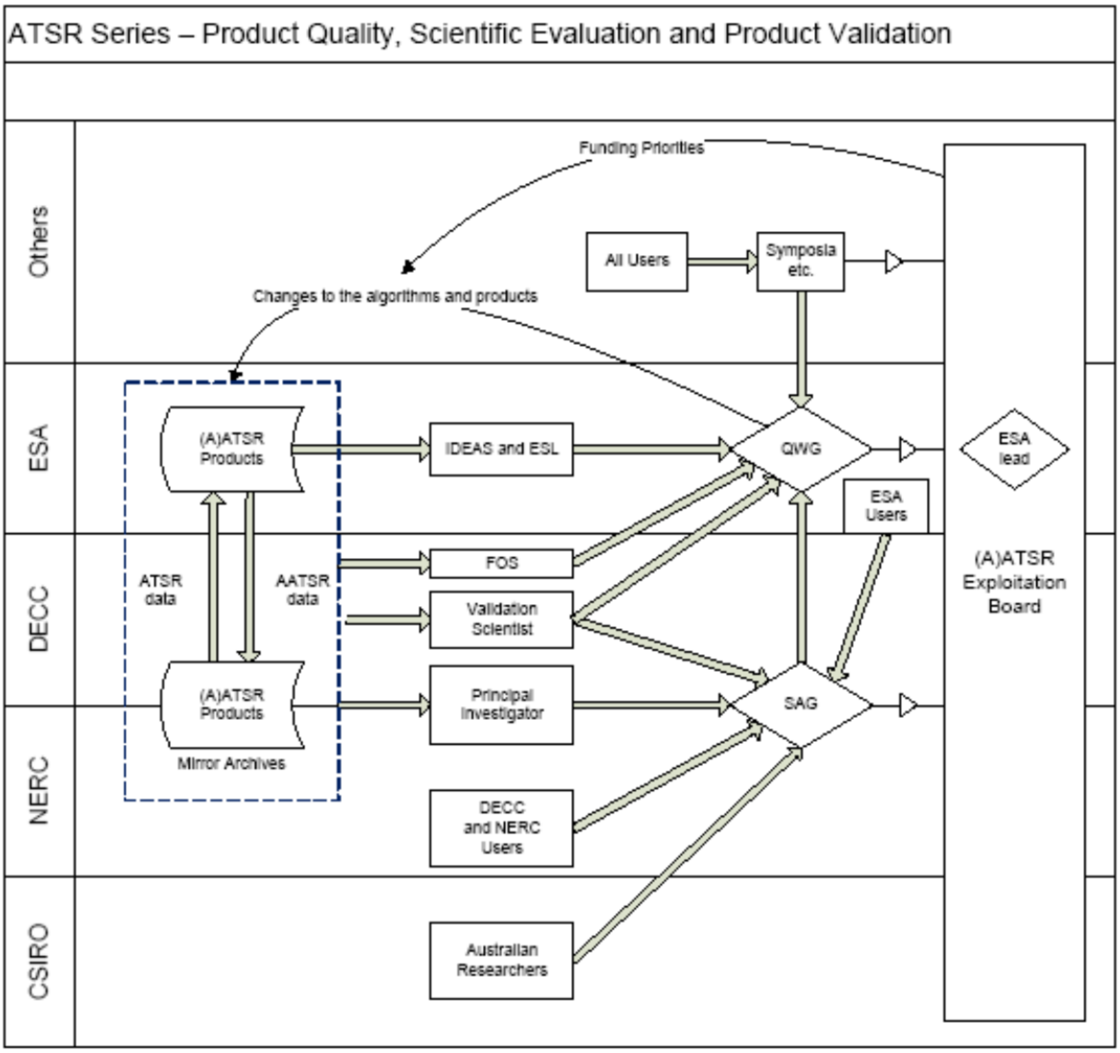

Figure 5-2: ATSR quality and product improvement cycle

Many of the actions described under this section are relevant to long-term data operations and therefore apply not only to the past 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 Copernicus and the ESA CCI programmes.

10.8 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 should be adopted by the the SAG, for the revision of existing operational products and the roll-out of new ATSR and SLSTR (operational) products.

2. A formal process for identification of “official” ATSR products, with increased emphasis on consistent processing of all four data records, i.e. including SLSTR.

3. Support for the development of new algorithms to realise the full potential of ATSR and SLSTR data.

4. Support for verification and validation activities of all SLSTR “official” products”, led by a 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 ATSR data, for example as was done 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 ATSR record from all four instruments including SLSTR.

8. Further development of interfaces to the ATSR data archive, to facilitate easy user exploitation and to ensure a combined and consistent store of ATSR and SLSTR data.

11 REFERENCE DOCUMENTS

RD001: M.R. Allen, C.T. Mutlow, G.M.C. Blumberg, J.R. Christy, R.T. McNider and D.T. Llewellyn-Jones, 1994. "Global change detection," *Nature*, *370*, pp. 24-25

Available at: www.nature.com/nature/journal/v370/n6484/pdf/370024b0.pdf

RD002: Ohring, G., Wielecki, B., Spencer, R., Emery, B., & Datla, R. (2005). Satellite instrument calibration for measuring global climate change – Report of a workshop. *Bulletin of The American Meteorology Society*, 86, 1303-1313, http://dx.doi.org/10.1175/bams-86-9-1303.

RD003: Systematic Observation Requirements for satellite-based Data Products for Climate, 2011 update, Supplemental Details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in support of the UNFCC (2010 update) GCOS Implementation Plan", GCOS-154, December 2011.

APPENDIX A: LIST OF ACRONYMS

AATSR	Advanced Along-Track Scanning Radiometer
ATSR	All three ATSR instruments
AEB	ATSR Exploitation Board
AEP	ATSR Exploitation Plan
AO	Announcement of Opportunity
AOD	Aerosol Optical Depth
ARC	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
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: ATSR PRODUCTS

B.1 ATSR-1 and -2 Products

ATSR-1 and -2 information is extracted from http://www.atsr.rl.ac.uk/dataproducts/index.shtml

B.1.1 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 DECC and ESA ATSR Archive.

B.1.2 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.1.3 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.1.4 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.1.5 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.

B.1.6 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.1.7 ATSR Product Quality Evolution Summary for ATSR-1 and ATSR-2

ATSR-1 and ATSR-2 are now available as Envisat-style products in order to be consistent with the AATSR data products. Therefore also refer to Section B.3 for details on the AATSR products. A Technical Note (APP-TN-005) describes the differences for ATSR data in Envisat format and is available from the ESA library here.

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 V2 and V2.1 of the Archive:

L1B (Envisat "TOA") Products:

1. Improved colocation between the nadir and forward views
2. Improved and consistent calibration of the reflectance channels

L2 (Envisat "NR" and "AR" products):

1. Improved SST coefficients based on knowledge from the ARC project

B.2 ATSR-1 and -2 Processing History

B.2.1 ATSR-1 and -2 Reprocessing Status

B.2.1.1 Archive V2.1 (current version) for ATSR-1 and ATSR-2

Processor versions used:

L1B Processor:

STEP 1.4 used for all of the ATSR-1 data and ATSR-2 data

L2 Processor:

Proto2-L/0.7 Used for data acquired throughout both missions

Completeness

ATSR-1 data:

All available input orbits between August through October 1991 (commissioning phase) and November 1991 through December 1997 (operational phase). *Note: After the nominal end-of-mission in early June 1996 there are only occasional, brief restarts thereafter.*

ATSR-2 data:

All available input orbits between June through July 1995 (commissioning phase) and August 1995 through June 2003 (operational phase up to end of on-board tape-recorder life). *Note: Some ATSR-2 data after the loss of the tape recorders are available, as direct downlinks to ground stations were used where available. However, data from these periods have not yet been processed from the raw data received and so are not available in the archive.*

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)

B.2.1.2 Archive V2.0 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)

B.2.1.3 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.

B.2.2 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 ATSR Archive: Only v350 and v356 were used to generate UBTs for the ATSR archive.

B.2.3 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.3 AATSR Products

AATSR product information is extracted from the AATSR Flight Operations and Data Plan (FODP) and the ESA website at: https://earth.esa.int/web/guest/data-access/browse-data-products

B.3.1 AATSR Product Summary Table

Processing Level	Description	Product ID Size (MB)
Level 0	AATSR 'Raw Data'	ATS_NL__0P 490 MB / orbit
Level 1B	Gridded brightness temperature and reflectance	ATS_TOA_1P 764 MB / orbit
Level 2	Sea and Land geophysical parameters	ATS_NR__2P 133 MB / orbit
Level 2	Spatially Averaged Geophysical Product (50 x 50 km, 17 km x 17 km, 30 x 30 arcminutes and 10 x 10 arcminutes per cell)	ATS_AR__2P 56 MB / orbit
Level 2	Spatially Averaged Geophysical Product – subset (10 x 10 arcminutes per cell)	ATS_MET_2P ~5 MB / orbit
Level 2	ARC_L2P Sea Surface Temperature Product 1 km x 1 km, netCDF format	UPA-L2P/L3U 45 MB / orbit
Level 2	ARC_L2P Averaged Sea Surface Temperature Product 0.1 degree, netCDF format	UPA-L3U 0.7 MB / orbit
Level 2	Land Surface Temperature Product 1 km x 1 km, netCDF format	ATS_LST_2P 69 MB / orbit
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[1] *datasets in Envisat and netCDF format.*

The L1B dataset should change only rarely in the future as it is an engineering product derived from the instrument characteristics.

The L2 products will change as improved knowledge and methodologies for the retrieval of SSTs and LSTs is gained.

[1] *Definition: Consolidated products are time ordered with no overlaps or data gaps (except when the data are genuinely unavailable, for example if the instrument was not operating).*

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

SPH = Specific Product Header, further description record (specific to product type).

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	Gridded brightness temperature and reflectance
DESCRIPTION	The product contains geolocated, radiometrically and geometrically corrected brightness temperature/radiance images; nadir and forward views are colocated.
COVERAGE	512 km x 40 000 km
THROUGHPUT	1 product per orbit (100 minutes)
GEOMETRIC RESOLUTION	Resampled 1 km x 1 km along track
MAXIMUM SIZE	Max. 764 MB / orbit
RADIOMETRIC RESOLUTION	Coded on 16 bits/sample
RADIOMETRIC ACCURACY	for VIS/NIR channel 5% relative to the sun for IR channels < 0.1 Kelvin
DATASET	MPH SPH MDS ADS
AUXILIARY DATA	Orbit state vectors, Time correlation parameters, Summary quality information, Image grid pixel lat/long, Scan pixel x/y, Nadir and Forward view solar angles, Visible calibration coefficients, Nadir and Forward scan and pixel number
NOTES	Available as multiple of scene size 512km x 512km or full orbit

PRODUCT ID	**ATS_NR__2P**
NAME	Geophysical product
DESCRIPTION	This product contains various geophysical parameters for each pixel, dependent on the classification of the pixel. Parameters include SST over oceans, LST and NDVI over land, and Brightness Temp for unclassified pixels.
COVERAGE	512 km x 40 000 km
THROUGHPUT	1 product per orbit (100 minutes)
GEOMETRIC RESOLUTION	Resampled 1 km x 1 km along track
MAXIMUM SIZE	Max. 133 MB / orbit
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	MPHSPH MDS ADS
AUXILIARY DATA	Surface identification flags included in the Level 1B product, Orbit state vectors, Time correlation parameters, Summary quality information, Image grid pixel lat/long, Scan pixel x/y, Nadir and Forward view solar angles, Nadir and Forward scan and pixel number
NOTES	Available as multiple of scene size 512km x 512km or full orbit

PRODUCT ID	**ATS_AR__2P**
NAME	Spatially averaged geophysical product
DESCRIPTION	This product contains average measurements for 50 km, 17 km, 30 arc minutes, and 10 arc minute cells.
COVERAGE	512 x 40 000 km
THROUGHPUT	1 product per orbit (100 minutes)
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	Max. 56 MB / orbit
RADIOMETRIC RESOLUTION	0.01 degrees for SST
RADIOMETRIC ACCURACY	0. 5 degrees Kelvin for SST
DATASET	MPH SPH MDS
AUXILIARY DATA	Orbit state vectors, Time correlation parameters
NOTES	Available as full orbit only

PRODUCT ID	**ATS_MET_2P**
NAME	Spatially averaged geophysical product subset
DESCRIPTION	This product contains spatially averaged sea surface temperatures extracted from the ATS_AR__2P product.
COVERAGE	512 x 40 000 km
THROUGHPUT	1 product per orbit (100 minutes)
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
AUXILIARY DATA	Orbit state vectors, Time correlation parameters
NOTES	Available as full orbit only

PRODUCT ID	**UPA-L2P**
NAME	ARC_L2P Sea Surface Temperature product
DESCRIPTION	This product contains dual-view SST calculated using the ARC SST retrieval and cloud screening (which differ from the methods used for the ATS_NR__2P products). Products also contain the ATSR Saharan Dust Index and the estimated clear-sky probability. This product is available in netCDF format, compliant with GHRSST GDS 2.0.
COVERAGE	512 km x 40 000 km
THROUGHPUT	1 product per orbit (100 minutes)
GEOMETRIC RESOLUTION	Resampled 1 km x 1 km along track
MAXIMUM SIZE	Max. 45 MB / orbit
RADIOMETRIC RESOLUTION	(*not available*)
RADIOMETRIC ACCURACY	(*not available*)
DATASET	NetCDF4-classic data file
AUXILIARY DATA	Lat/lon, Solar zenith angles, Uncertainty estimates, Quality level indicator, Wind speed, Sea ice fraction
NOTES	Available as full orbit only

PRODUCT ID	**UPA-L3U**
NAME	ARC_L2P averaged Sea Surface Temperature product
DESCRIPTION	This product contains dual-view SST, ASDI and clear sky probability averaged (from the UPA-L2P products) onto a global 0.1 degree grid
COVERAGE	512 km x 40 000 km
THROUGHPUT	1 product per orbit (100 minutes)
GEOMETRIC RESOLUTION	0.1 degrees
MAXIMUM SIZE	Max. 0.7 MB / orbit
RADIOMETRIC RESOLUTION	(*not available*)
RADIOMETRIC ACCURACY	(*not available*)
DATASET	NetCDF4-classic data file
AUXILIARY DATA	Lat/lon, Solar zenith angles, Uncertainty estimates, Quality level indicator, Wind speed, Sea ice fraction
NOTES	Available as full orbit only

PRODUCT ID	**ATS_LST_2P**
NAME	Land Surface Temperature product
DESCRIPTION	This product contains full resolution nadir-view LST calculated using the same retrieval method used for the ATS_NR__2P products, but with improved auxiliary information applied and a

	different cloud screening method.
COVERAGE	512 km x 40 000 km
THROUGHPUT	1 product per orbit (100 minutes)
GEOMETRIC RESOLUTION	Resampled 1 km x 1 km along track
MAXIMUM SIZE	Max. 69 MB / orbit
RADIOMETRIC RESOLUTION	(*not available*)
RADIOMETRIC ACCURACY	(*not available*)
DATASET	NetCDF4-classic data file
AUXILIARY DATA	Lat/lon, Solar zenith angles, Uncertainty estimates, Quality level indicator, Wind speed, Sea ice fraction
NOTES	Available as full orbit only

B.4 AATSR Processing History

The following information is taken from the AATSR IPF Change Log (IDEAS-VEG-OQC-REP-0225), issue 3, 18 March 2013.

28 February 2013 – ARC L2P V1.1

A complete change of L2P processor has taken place, and new ARC L2P (and L3U) products in GHRSST Data Specification (GDS 2.0) netCDF format will be produced. The ARC L2P products contain ARC SSTs generated from the reprocessed L1B products, i.e. the L2P SSTs are no longer extracted from the L2 NR products. The ARC L2P processor includes:

- Bayesian cloud detection;
- The ARC SST retrieval algorithm;
- The ARC SST uncertainty model.

The L3U product is an entirely new product for AATSR and contains the ARC L2P dataset remapped onto a regular lat/lon grid.

20 December 2012 – IPF V6.05 and auxiliary data updates (SST, CL1, CH1, PC1, VC1)

IPF V6.05 was in preparation for operational deployment when the Envisat end of mission was declared on 09 May 2012. Although it did not become operational, V6.05 is used in the third AATSR reprocessing in 2013; the date given above is that on which the installation of the processor in readiness for the reprocessing was accepted.

In summary, the specific improvements are:

- SST retrievals within the Envisat L2 product improved via the use of updated SST coefficients from the ARC project (update to ATS_SST_AX);
- Cloud test corrections, which may improve detection (update to ATS_CL1_AX);
- Colocation between forward and nadir views improved (update to ATS_CH1_AX);
- Absolute nadir geolocation accuracy improved (update to ATS_CH1_AX);
- Improved extraction of visible calibration data (update to algorithm and ATS_PC1_AX);
- A regenerated VC1 dataset containing the best-available measured long-term drift corrections was delivered (L1B headers contain the name of the drift table used in the viscal long-term drift correction).

The corrections made were:

- Reference document field in the MPH was corrected to indicate the right version;

- A debug option was removed when building the IPF (this had caused spurious processing failures);
- MPH/SPH fields mismatch in the identification of OSV files was corrected.

18 October 2010 – auxiliary data updates for mission extension: LST, CL1, PC1

An update of some auxiliary files was required for the new phase:

- ATS_LST_AX file: Phase MPH field set to X (in line with the other ADFs; contents unchanged);
- ATS_CL1_AX: validity range was extended to cover the whole mission (contents unchanged);
- ATS_PC1_AX: file contains the orbit period, so two versions were now required, one with the orbit period before the mission extension and one with the orbit period after the mission extension, with validity ranges set appropriately.

16 June 2010 – IPF V6.03

In preparation for the Envisat 2010+ mission extension, the IPF was updated to use the new Envisat CFI V5.8.1 (the CFI software is a set of pre-compiled libraries for timing, coordinate conversion, orbit propagation, satellite pointing and target visibility calculations). At the same time, the opportunity was taken to ensure that the AST confidence word was initialised correctly.

04 November 2009 – L2P V1.5.

This version of the processor changes the order of two records in the metadata (FR_Revision_History and FR_Last_Revision_Date are swapped); no changes were introduced to the L2P products themselves.

28 September 2009 – IPF V06.02L02

The AATSR processor platform was ported from AIX to Linux, changing the IPF version number to V06.02L02. Please note that this is NOT a change of algorithm and due to an extensive validation process the change should be transparent to users.

29 May 2009 – L2P V1.5

This version implemented the following changes:

- Inclusion of AOD information (field aerosol_optical_depth);

- Inclusion of satellite observation minus SST analysis (field DT_analysis);
- Latitude and longitude coordinates are now provided for the pixel centre;
- UTC keyword now contained in start_time and stop_time fields in MPH;
- The view difference dataset (atsr_dual_nadir_diff) has been masked so as to provide values only for pixels where the SST is provided.

26 February 2009 – L2P V1.1 (no change in processor version number)

The processor was updated to change the formatting of the xml files associated with the L2P product; no change was made to the content of the L2P product itself.

01 December 2008 – L2P V1.1

Initial version (for NRT data only).

Generation of the AATSR L2P product was initiated by the DUE Project Medspiration, as part of the European contribution to GHRSST. In December 2008 ESA took over the responsibility of producing L2P products as part of AATSR operations.

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.

02 July 2007 – IPF V6.01

The patch introduced with IPF V6.01 corrects for an erroneous calculation of the ANX during consolidated processing, leading to missing Viscal GADS in the L1B products.

28 March 2007 – IPF V6.0 and auxiliary data update (ATS_CL1_AX)

IPF V6.0 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 file was delivered.

01 February 2007 – auxiliary data update: ATS_VC1_AX

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

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 (see http://earth.esa.int/pcs/envisat/aatsr/reports/cyclic/).

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.

15 June 2006 – processing configuration update

A configuration file governing the behaviour of the AATSR IPF was updated so that it used the averaged data cell size value (50 km) as given in the ATS_PC2_AX file rather than overriding with a fixed value (48 km). This change did not require any modification to the IPF or auxiliary data.

07 December 2005 – auxiliary data update: ATS_SST_AX

Revised SST retrieval coefficients were introduced in the ATS_SST_AX file. 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.

29 November 2005 – auxiliary data update: ATS_VC1_AX

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

14 December 2004 – auxiliary data update: ATS_GC1_AX

New ATS_GC1_AX file supplied, to correct the application of the 1.6 micron non-linearity correction.

12 August 2004 – auxiliary data update: ATS_PC1_AX

A new ATS_PC1_AX file was supplied, updated with revised solar irradiance data (carried through into the output Viscal GADS in the L1B product).

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.

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).

January 2003 – IPF V5.55

Update containing modifications to the Viscal algorithm, and associated ATS_PC1_AX 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.

November 2002 – auxiliary data update: ATS_CH1_AX

New ATS_CH1_AX file submitted to the PDS containing updated misalignment parameters, AOCS parameters and regridding tolerances. This improved the colocation between the forward and nadir views.

October 2002 – auxiliary data update: ATS_INS_AX

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

September 2002 – auxiliary data update: ATS_VC1_AX

New ATS_VC1_AX 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).

July 2002 – IPF V5.52

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

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.

February 2002 – IPF V5.01

Launch version.

B.5 ATSR Data Availability

ESA Users

The ATSR dataset is made available as follows:

- FTP: ftp://ats-ftp-ds.eo.esa.int (Full mission dataset – all product types)
- HTTP: http://ats-merci-ds.eo.esa.int/merci (Area/time extraction and bulk download via MERCI – for ATS_TOA_1P and ATS_NR_2P products)

Additionally, data can be distributed on NAS disks for large requests.

Customers already registered for access to the ATSR service can use the same UserID and Password for accessing the new servers. For new users, access to the dataset is provided upon Fast Registration at:

https://earth.esa.int/web/guest/pi-community/apply-for-data/fast-registration.

Users are encouraged to access the improved SST data within the newly generated UPA-L2P/L3U netCDF products and the improved LST data within the newly generated ATS_LST_2P products, rather than the ATS_NR__2P products. (Note: improved LST products are not yet available for ATSR-1 or ATSR-2.) The UPA-L2P/L3U and ATS_LST_2P products are available via the FTP link above.

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 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. Up to date information on data availability can be found at the NEODC webpage at http://www.neodc.rl.ac.uk

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.

RD003 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 ATSR. These ECVs are identified in Table 1 with an asterisk. For each ECV listed below, a reference is provided to a section in RD003.

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

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	Surface wind speed and direction; precipitation; upper-air temperature; upper-air wind speed and direction; water vapour; cloud properties; Earth radiation budget (including solar irradiance); carbon dioxide; methane and other long-lived greenhouse gases; and ozone and aerosol properties, supported by their precursors.
Oceanic	Sea-surface temperature; sea-surface salinity; sea level; sea state; sea ice; ocean colour
Terrestrial	Lakes; snow cover; glaciers and ice caps;, ice sheets; albedo; land cover (including vegetation type); fraction of Absorbed Photosynthetically Active Radiation (FAPAR); Leaf Area Index (LAI); above-ground biomass; fire disturbance; soil moisture.

Table 2: Atmospheric ECVs

ECV	Comment
Upper-air Water Vapour Profile Product A.5.1 - see RD003 3.1.5)	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. Water vapour is a candidate for future ECV projects but the contribution of ATSR would have to be demonstrated relative to microwave and

	VIS/NIR.
Cloud Properties (ECV Product A.6.1-6 - see RD003 3.1.6) Cloud amount, top pressure and temperature, optical depth, water path and effective particle radius	Strong area for ATSR Products. CCI Clouds has currently produced AATSR data for 2007-2009. Will be producing ATSR for 1995 onwards to 2012, and combined AATSR/MERIS for the Envisat mission. (See Chapters 4 and 7)
Aerosol Properties (ECV Product A.10.1-10.2 - see RD003 3.1.10) Aerosol optical depth, aerosol single scattering albedo	Strong area for ATSR Products. Data for 1995-2012. (see Chapters 4 and 7)

Table 3: Oceanic ECVs

ECV	Comment
Sea Surface Temperature (SST) (ECV Product O.1 - see RD003 3.2.1)	Main part of existing ATSR dataset. Climate datasets produced from 1991 to 2012 through ARC and CCI SST. (see Chapters 4 and 5)
Sea Ice (ECV Product O.5 - see RD003 3.2.5)	Proposals for developing an ATSR Sea-Ice product for sea ice extent and edge have been made. It is an increasingly important area for climate change and more priority is needed in this area (see Chapters 4 and 8)

Table 4: Terrestrial ECVs (including Emerging ECVs)

ECV	Comment
Fire Disturbance (active fires supplemental to ECV Product T.10 - see RD003 3.3.10)	ATSR data have been used in the CCI Fire project, but no clear products. ATSR data are the inputs to the ESA Fire Atlas. Both fire and burned area data should be investigated, especially for SLSTR (see Chapters 4 and 6)
Land Cover (ECV Product T.5.6.1 - see RD003 3.3.6)	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. 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.7 - see RD003 3.3.7)	Generation of fAPAR fom ATSR data is in progress.
Leaf Area Index (LAI) (ECV Product T.8 - see RD003 3.3.8)	
Land Surface Temperature (LST) (Product T.12 Supporting other ECVs see RD003 3.3.12; emerging but not yet primary ECV)	Prototype climate data records are being produced for the ATSR datasets but are currently being validated (see Chapters 4 and 6).
Lake Surface Temperature	Lake surface temperature products have been produced

(Not yet an ECV – see RD002 3.3.1)	for ATSR data, and examined for long-term trends. A specific climate product should be developed (see Chapters 4 and 6)