THE LESSONS LEARNED FROM AATSR AND BRIDGING THE GAP TO SLSTR

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ABSTRACT

During the AATSR Mission there were a number of developments which were crucial to the final success of the whole 3-instrument ATSR programme. In this synopsis, the main successes and the lessons learned as a result of these are briefly described and summarised. The areas of activity which benefitted were scientific algorithm refinement and re-processing, validation, and provision of data to operational users. Also, the issues involved in addressing the data-gap between AATSR and SLSTR, which is now a reality, are discussed in the light of the fact that AATSR SST data are contributing to the climate record. The processes of gap-bridging and gap-filling are defined and discussed. The strategies proposed for these are also described.

1. INTRODUCTION

The Advanced Along-Track Scanning Radiometer (AATSR) was an 'Announcement of Opportunity' instrument flying as one of the payload elements on the Envisat satellite. The operational orientation of AATSR can be seen in Fig. 1.

AATSR was a thermal infrared imaging radiometer, the third in the ATSR series, following ATSR-2 on ERS-2 and, before that, ATSR-1 on ERS-1. The ATSR instruments were designed to measure sea-surface temperature (SST) to climate standards of accuracy and stability.

AATSR was undoubtedly one of Envisat's many great success stories; not only did AATSR demonstrate the ability to measure global SST to higher levels of accuracy than previously achievable, it gained the full acceptance of the climate research community. It also pioneered the largely uncharted path from experimental innovation to operational applications.

AATSR was highly productive scientifically, as indicated by the Special Issue of the scientific journal, Remote Sensing of Environment (RSE), which was devoted to major results from AATSR and published in 2011.

In this synopsis, some of the most important of the many lessoned learned from the mission are briefly described.

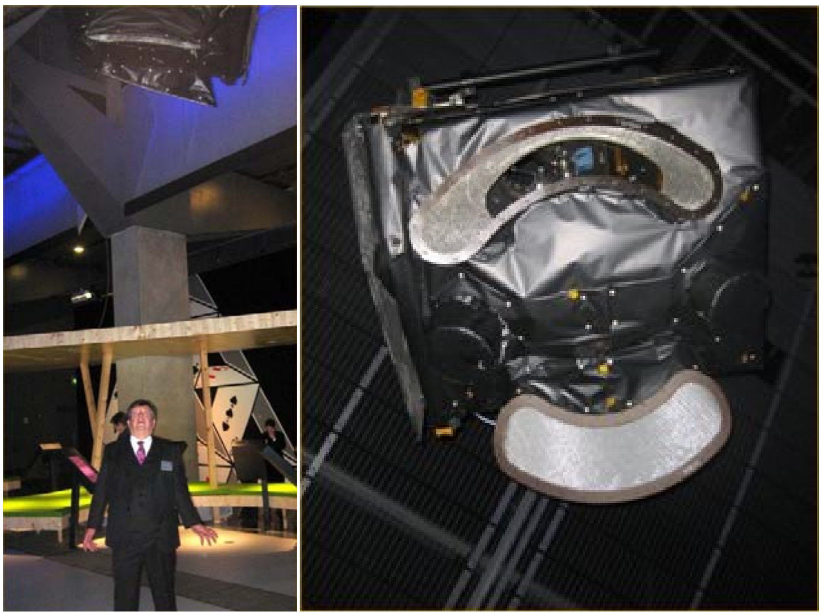

Figure 1: In London's Science Museum, the AATSR Structural/Engineering Model is on display as part of their new exhibition "Atmosphere – Exploring Climate Science". The panel on the left includes an example of an anthropogenic species for scaling purposes.

2. AATSR AND SCIENCE

2.1 Special Issue of RSE Journal

Many of the main scientific achievements of AATSR are summarised in the ATSR special issue of RSE (2011), doi:10.1016/j.rse.2011.06.002. In this issue, there are 18 papers covering validation, product development, algorithm development, as well as land applications and, atmospheric applications etc.

2.2 The ARC Project and Climate Applications

Throughout the three ATSR missions, considerable effort was devoted to algorithm improvement and these efforts were finally brought to maturity, during the last five years, by the ARC Project (ATSR Reprocessing for Climate). The objectives of ARC were to generate – and make fully available to users - a global ATSR SST data set of at least 15 years' duration and of sufficient quality to meet the requirements of the climate record, by addressing all known algorithmic and instrumental issues which significantly affect the quality of ATSR data.

ARC was carried out by a consortium led by C Merchant at the University of Edinburgh. The ARC consortium also included the University of Leicester, the UK Met Office Hadley Centre and the National Oceanography Centre, Southampton (NOCS). These consortium members represented virtually all the expertise required to address the necessary algorithmic problems and, very importantly, it included a data-user, the Hadley Centre for Climate Prediction and Research, who had a clearly defined need for a 15-year time-series of global SST data to meet the very demanding standards of accuracy and stability. The inclusion of a user, and the requirement to deliver a re-processed data-set which satisfied the user's needs, were key aspects of the project and key to its success.

Regarding the accuracy achieved: the global uncertainties in SST were reduced to <0.1˚C under all conditions and better than .02 ˚C under optimum conditions (i.e. 3-channel by night). The long-term stability demonstrated (in the Tropics) was ~0.03 ˚C/decade. These figures fully meet the stated needs of climate science.

In order to achieve the full potential of the data, it is necessary to:

a) Understand the data, how they are produced and the likely causes of any evident anomalies

b) Find and engage the appropriate expertise needed to address the relevant issues

c) Form a team with clear objectives

d) Produce the data-sets for general access within an agreed time-scale

As mentioned above, it is essential to engage users/customers in the development team. This is different from an "Algorithm Working Group" which will often exist and function on an *ad hoc* basis. The key differences are that the project works formally in response to user needs and generates output which is 'signed off' by the user representative in the team.

Proper funding arrangements are, of course, absolutely essential if the effort is to be structured and have defined objectives and output. The ARC Project received funding from the UK Natural Environment Research Council (NERC), under a 'Knowledge Transfer' scheme, where the incorporation of users in the consortium was a requirement. There were also contributions from UK MoD and the UK Department for Energy and Climate Change (DECC), as potential beneficiaries of 'Knowledge Transfer'. It is important to stress this aspect, because there is little doubt that the success of the ARC Project depended heavily on the requirement to meet a defined user need within the scope (and timetable) of the project.

The ARC data-set has shown that the 20+ years of ATSR SST are clearly of climate quality. Moreover, the ATSR data are independent and therefore an important new element to the climate record.

2.3 Lesson Learned from ARC

Throughout the three ATSR missions there have been individuals and ad hoc groups working on the development and refinement of the data-processing system, resulting in a large but rather diffuse body of knowledge about the possibilities for improvement. However, it required a well-defined and properly structured project, with clearly defined user requirements, scope, objectives and output within an agreed timetable. It should go without saying that, as with all cooperative activities, effective direction and management from the project leader is an essential element. In addition, a particularly important and unusual feature of the ARC consortium is that the users/customers were explicitly involved as consortium members, ensuring that the output did meet their needs.

3. VALIDATION

The Validation Plan, developed in the years preceding the launch, should identify the following:

- Early verification activities
- On-going mission activities

The plan must assign and define the overall responsibility for a timely and effective validation programme.

3.1 For the Early Stages of the Mission

It should be a paramount objective to achieve, by the end of the Commissioning Phase, a limited, but reasonable, level of confidence in the accuracy of the data-products at the outset of data-release to users.

It is necessary to make explicit decisions on:

- The data-products to be verified in the initial evaluation
- *In situ* data must be reliable, flexible and of limited complexity
- What level of coverage and accuracy of reference data are needed?
- The scheme for early mission validation must be feasible so that it can be completed in the agreed time-scale, ideally not more than the first year of the mission.
- Decide what data collection system is to be used for reference data
  - autonomous systems have great advantages
- It is essential, at all times, to maintain close interaction with ALL providers of reference data for cal/val. Perhaps a purpose-designed interactive website could provide an effective means of achieving this.
- Match-up processing should be done routinely, preferably to an agreed timetable
- Agree time-scales for delivery of the satellite data-products for match-up processing
  - data formats (CF compliant NetCDF)
  - provide availability details for ALL orbits even if they are missing/lost
  - have the capability to process data offline so that multiple processing chains can exist for processor upgrades and evaluation prior to release
  - when offline products are to be used for match-ups, it is important to provide quality control information for offline products

Finally, in the collection, pre-processing (where necessary) and formatting a delivery of reference data, it is vitally important to **provide uncertainties with all measurements, broken down into systematic and random components.**

4. THE LARGEST LESSON LEARNED DURING THE MISSION

It is arguable that the greatest achievement of AATSR was to gain acceptance of the SST data by operational users but why did this take 15 years after the launch of ERS-1?

The answer lies in the GODAE, Medspiration and GHRSST Programmes. What did they do?

1) **The Global Oceans Data Assimilation Experiment - GODAE**

   - This was a WCRP/GCOS/GOOS programme
   - It recognised the existence of high-quality satellite data
   - It also realised why data were not being used by the operational users needing it
   - The GODAE requirements were:
     - must deliver data in appropriate Time-scales
     - must deliver data in appropriate Data-Formats
     - must deliver data with appropriate Error information

   otherwise, operational users will be unable to use the new data within their existing assimilation systems.

2) **Medspiration**

   - An ESA Data User Element (DUE) project
   - Initially aimed to provide SST from European waters to operational users
   - After much internal discussion, ESA agreed to widen scope to global!

   Thus, global AATSR SSTs became available on a 'same day' basis.

3) **GODAE High Resolution SST Pilot Project - GHRSST**

   (Post-GODAE, 'G' stands for 'Group for')

   - International inter-agency project (with ESA-funded Project Office)
   - Organised the generation of operational (L2P Format) SST products from ~7 satellites
     - Accepted format (NetCDF)
     - Error statistics for each data-point
     - Timely processing and delivery

GHRSST led to the creation of an official ESA SST L2P product, bringing to fruition the pioneering Medspiration work.

5. SUMMARY OF LESSONS LEARNED

Of the many lessons which are explicitly or implicitly referred to in this synopsis, the most important of these, which the author wishes to record and communicate to ESA are summarised in the table below.

Table 1: Lessons learned from the AATSR Mission

Topic	The Lessons
Data-product & development refinement	Need to form consortium comprising relevant expertise AND user/customer representation
	Generate the data-sets and archive them for general access
	This activity requires a proper funding framework
Validation programme	The Validation Plan needs to define, in addition to activities during the main mission period, early mission phase activities and objectives, which are necessarily limited, but they must be feasible within the time-scale.
	Also, the Validation Plan must assign and define the overall responsibility, including that of the Validation Scientist, Manager or Coordinator (depending on the chosen nomenclature) for a timely and effective validation programme.
	Validation teams must make clear decisions and agree on: • Data-collection programmes • Timescales for data-processing and reporting • Data-formats • Provision of uncertainty information (both bias and random components)
Development of user community	Must consult users and understand their constraints. What is preventing them using your excellent data?
	It is important, especially in the case of 'power users', to adapt where necessary, products, formats and delivery methods to meet the needs and constraints of the users. This is often a major undertaking requiring research and extensive international coordination. ESA's DUE programme is an excellent and proven vehicle for achieving this.
General:	It is essential to listen to and understand the constraints and requirements of the users – and then to act in response.

6. BRIDGING AND FILLING THE GAP

6.1 Why is the SST Data-Gap important?

The AATSR SST data set has now reached standards of accuracy, stability and traceability which qualify it to contribute to the SST Climate Data Record (CDR). Faced with a minimum 2-year data-gap, there are two needs:

1) To bridge the gap
2) To fill the gap

These two objectives will be briefly defined and the possible plans for addressing them will be discussed.

6.2 Bridging the Gap

The objective here is to ensure that the data collected just before the data-gap and the data collected immediately upon resumption of the data-collection service are, in each case, compared to traceable reference standards, preferably using the same reference data system. Thus the data-record is resumed with the same, totality compatible, calibration.

To achieve this, there is a requirement for an SI-standard traceable reference to calibrate AATSR data-products at Envisat End of Life and SLSTR at the beginning of the Sentinel-3 mission. Experience with AATSR has demonstrated that ship-borne radiometers can do this. However, the measurement systems need to be made available, with the appropriate calibration procedures applied. It is suggested that the AATSR sampling strategy, which has been in place for the last two years of the Envisat mission, is replicated for SLSTR reference measurements to be carried out for at least the first two years of the S-3 mission.

To summarise:

- There is a need for an SI-standard traceable reference to calibrate AATSR data-products at End of Life and SLSTR at Beginning of Life
- Ship-borne radiometers can do this
- The AATSR sampling strategy should be replicated for SLSTR reference measurements

It should be recognised that *in situ* measurements are also required to supplement the ship-borne radiometers. Drifting buoys are needed to evaluate spatial biases (ideally 2 years of AATSR and 2 years of SLSTR data). The Argo data needs to be tested for stability, ideally within the AATSR period and its role compared to that of GTMBA (note independence of Argo).

6.3 Filling the Gap

Whereas gap-bridging only requires consistent and traceable calibration of the data-products at the beginning and end of the interruption to data-service, gap-filling seeks to monitor the geophysical parameter with alternative data-sources, in order to monitor details of geophysical behaviour during the interruption. Is it feasible to use an alternate satellite system for this purpose? The following points need to be observed:

- There is a need to match the calibration and sampling performance of AATSR
- Of the currently available SST sensors, MetOp/AVHRR and MODIS have similar sampling characteristics
- Calibration of the SST data-products can be monitored with *in situ* reference data (radiometers) and, where necessary, empirical bias corrections can be applied

In this way, it should be possible to develop a non-AATSR satellite data stream to fill the gap, utilising MetOp AVHRR, IASI or MODIS. It is necessary to verify this alternative SST against AATSR data for at least 2 years and also to verify the alternative SST against SLSTR data for at least 2 years. Validating non-AATSR satellite data set needs to be done using ship-borne radiometers and *in situ* measurements as for AATSR/SLSTR. Taking these points into account, it should be feasible to use a non-AATSR satellite climate SST analysis to develop a SST-reference data stream for operational uses during the gap period.

6.4 Summary of a possible gap-filling and gap-bridging strategy for SST

The data gap between AATSR and SLSTR now poses a greater challenge to SST data continuity than anticipated.

Strategies for gap-bridging and gap-filling are proposed

- For Climate Users, gap-bridging is more important
- For Operational Users gap-filling is now an urgent need.

In order to appreciate the significance of the prospective 2-year gap in the SST record, it is instructive to consider Fig. 2, which shows a record of Global Monthly Averaged SST from ATSR-2 and AATSR. It clear that 2-year gap, if bridged to ensure continuity of calibration, would not have a deleterious effect on the overall picture of long-term global behaviour which this plot illustrates. However, if the 2-year gap were to have occurred, say, from 1997 to 1999, it would have excluded the strongest transitory feature of the plot, namely the effect upon global averaged temperatures of the record-breaking El Nino of that period! Thus is it is clear that, in order to study both the overall trend and the underlying transitory processes which contribute to climatic behaviour, it is essential to adopt strategies for both gap-bridging and gap-filling. Such strategies have been identified and are being put into action for the AATSR-SLSTR SST data-record.

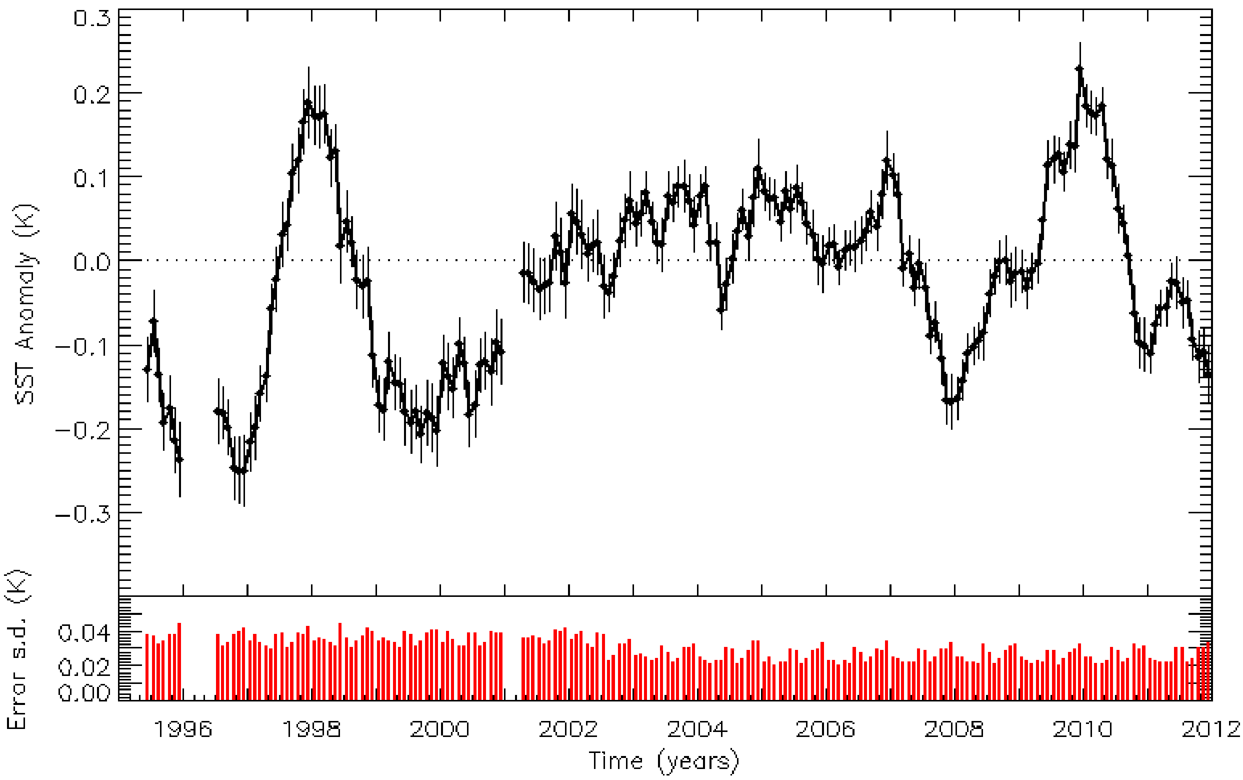

Figure 2: Global Monthly Averaged SST from ATSR-2 and AATSR

7. CONCLUSIONS

In over 20 years of experience of the three ATSR missions a number of lessons have been learned. Some of these have taken time to learn, partly on account of the fact that they can run counter to the instinctual priorities and objectives of research scientists. However there are also many technical, organisational and resource related reasons. As ESA enters the new programme of operational data-provision, it is essential that the most important of the many lessons learned are recorded and acted upon.

8. ACKNOWLEDGEMENTS

The author has been involved with ESA's Earth Observation programme since ATSR-1 was first proposed in the early 1980's and generous acknowledgements are due to very many colleagues at RAL, ESA and the University of Leicester, the UK Met office and the Universities of Southampton and of Edinburgh as well as many other institutes who have participated in and contributed to the ATSR programmes. It would be almost impossible to mention all the appropriate individuals, particularly because there will be inevitable accidental omissions from a very long list, but among the many whose work has directly affected the material of this synopsis, the author would like to mention the following: at the University of Leicester: Gary Corlett, who, as Validation Scientist for AATSR, originally raised many of the specific points recorded in this synopsis; especially those itemised in sections 3 and 6; Karen Veal, who provided the plot of Global Averaged monthly SST shown in Fig. 2**;** and John Remedios, also at the University of Leicester; at the University of Southampton, Ian Robinson and Werenfrid Wimmer; at the UK Met Office, Roger Saunders; at RAL, Dave Smith, Tim Nightingale and Chris Mutlow; and at Space ConneXions Ltd, Hugh Kelliher, who also has read and made many useful comments on the manuscript of this synopsis.

Finally, the author wishes to acknowledge the support of the UK Department of Energy and Climate Change (DECC), who have funded the AATSR programme steadfastly since 1993, shortly after AATSR's acceptance by ESA for the planned Envisat mission, as well as the support and cooperation of ESA staff at ESTEC, ESOC, ESRIN and ESA HQ, throughout the planning and implementation phases of the ATSR missions, in addition to their highly successful provision of the Envisat mission, which cannot be over-stated.