AATSR Validation Implementation Plan

PO-PL-GAD-AT-005 (3)

Version 3: Validation in Phase E

January 2003

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Document Change Record

Issue	Date	Affected Pages	Details
1.0	April 2001		Version 1
2.0	February 2002	All	Version 2 Draft
2.1	March 2002		Version 2
3.0	January 2003	All	Version 3: Validation in Phase E

Contents

1 Scope of document

The AATSR validation plan is made up of three parts. The first part, validation principles and definitions (AD1), gives an overview of the AATSR validation programme and sets out the principles behind it. The second part, the AATSR measurement protocol (AD2) discusses the measurements needed for validation, and recommends the instrumentation and procedures that should be used. Both of these documents have been written with the help of the AATSR SAG.

Part 3 of the AATSR validation plan is the Validation Implementation Plan (VIP) describing in detail the activities that will be performed to validate the AATSR data products. This document is Version 3 of the AATSR VIP, and describes validation activities after the Envisat validation workshop, in the Exploitation Phase (Phase E) of the mission.

2 Applicable Documents

AD1	PO-PL-GAD-AT-005 (1)	AATSR Validation Principles and Definitions
AD2	PO-PL-GAD-AT-005 (2)	AATSR Validation Measurement Protocol
AD3	PO-PL-RAL-AT-0501	AATSR Commissioning Plan
AD4	PO-RS-GAD-AT-0001	AATSR Science Requirements
AD5	PO-TR-RAL-AT-0024	AATSR Infra-red radiometric calibration report – Issue 1
AD6	PO-TR-RAL-AT-0023	AATSR Visible radiometric calibration report – Issue 2
AD7	PO-PL-GAD-AT-0006	AATSR Ground Segment Development Plan
AD8		MERIS Cal/Val Implementation Plan
AD9	SVDS-02	SCIAMACHY Validation Handbook
AD10	PO-PL-ESA-GS-1092	Envisat Calibration and Validation Plan
AD11	PO-TN-RAL-GS-10099	AATSR Algorithm Verification Plan

3 Acronyms

AATSR	Advanced Along Track Scanning Radiometer
ADS	Annotation Data Set
AIMS	Australian Institute of Marine Science
A/O	Announcement of Opportunity
ASTER	Advanced Space borne Thermal Emission and Reflection radiometer
ATBD	Algorithm Theoretical Basis Document
ATSR-2	Along Track Scanning Radiometer 2
AVHRR	Advanced Very High Resolution Radiometer
AWS	Automatic Weather Station
BADC	British Atmospheric Data Centre
BB	Black Body
BT	Brightness Temperature
Cb	CumuloNimbus
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEFRA	Department of the Environment, Food and Rural Affairs
DSD	Data Set Descriptor
ESA	European Space Agency
EOS	Earth Observation Science
FOS	Flight Operations Support
GBR	Great Barrier Reef
GPS	Global Positioning System
ISAR	Infrared Sea surface skin temperature Autonomous Radiometer
JRC	Joint Research Centre
L	Launch
LST	Land Surface Temperature
M-AERI	Marine Atmosphere Emitted radiance Interferometer
MAVT	MERIS and AATSR Validation Team
MDS	Measurement Data Set
MODIS	Moderate Resolution Imaging Spectroradiometer
MPH	Main Product Header
NCEP	National Centre for Environmental Prediction
NERC	Natural Environment Research Council
NDVI	Normalised Difference Vegetation Index
NWP	National Weather Prediction
OP	Operational Processor
PDS	Payload Data Segment
PI	Principal Investigator
PP	Prototype Processor
RAL	Rutherford Appleton Laboratory
SAG	Science Advisory Group
SCIPIO	Satellite Calibration and Interior Physics in the Indian Ocean
SISTeR	Scanning Infrared Sea Surface Temperature Radiometer
SODAP	Switch On and Data Acquisition
SPH	Specific Product Header
SST	Sea Surface Temperature
TOA	Top Of Atmosphere
VDP	Validation Data Provider
VIP	Validation Implementation Plan
VS	Validation Scientist

4 Validation requirements

The main objectives of the AATSR validation programme are to assess whether the AATSR instrument is returning global skin SST measurements and visible channel reflectances, which meet the scientific requirements of the mission in terms of accuracy. To meet these objectives, a number of validation activities will be carried out. Some of these are designated "core" activities, and are considered central to the validation programme. Other additional activities will be important for adding information and enhancing the core assessment made.

The validation programme was designed in two phases: an initial validation period from launch (L) up until the validation workshop at L + 9 months, and ongoing validation during the remainder of the mission. The objectives of the initial validation phase were:

- To determine whether the AATSR instrument is returning an acceptable global skin SST (±0.3 K, as defined in AD4).
- To make an initial assessment of the quality of the AATSR SST data products, in a limited number of sites and seasons. Making timely use of any tandem ATSR-2/AATSR mission, this should include the determination of any bias difference between the measurements made by AATSR and those made by ATSR-2.
- To assess the accuracy of the AATSR data retrieved over land (as defined in AD4). Eventually this will include both the reflectance values returned by the visible channels and the temperatures retrieved from the thermal channels.

The aims of the ongoing validation programme are:-

- To make a detailed assessment of the quality of the AATSR SST data products in an increasing number of sites and seasons.
- To monitor the quality of the AATSR data products over the duration of the mission (for example, to investigate the success of the SST retrievals in varying conditions such as periods of high aerosol contamination following a volcanic eruption). This is essential for ensuring continuity of the climate record.
- To validate new AATSR products. Ongoing validation will seek to validate new products as they are developed and made operational.

Due to the delay in data distribution to the validation PI's, initial validation phase objectives were not completed in the period up to the validation workshop. The initial validation phase will therefore run into Phase E, and is expected to be completed mid 2003. Validation for the ongoing validation programme will then continue.

As the initial and long-term objectives reflect, it is important that the validation programme carries out seasonal validation, regional validation, long term monitoring and the validation of new products. ATSR-2/AATSR cross validation is also an important component.

By addressing these objectives, the validation programme aims to provide assurance of data quality and accuracy for applications such as climate change research, investigate a varied and representative range of geophysical conditions and seasonal cycles, and monitor any instrumental drifts and other artefacts.

5 AATSR Data Products

Table 5-1 summarises the AATSR Data products. After reception on the ground, the raw data are converted into a Level 0 product. This consists of a chronological sequence of records, each containing a single instrument source packet, and with each source packet representing one instrument scan. Level 0 data are processed to give, firstly, the Level 1b and then the Level 2 product. Level 0 data are not routinely available to users.

Product ID	Name	Description
ATS_NL__0P	Level 0 Product	• Instrument source packet data
ATS_TOA_1P	GBTR	• Full resolution top of atmosphere BT/reflectance for all channels and both views. • Product quality data, geolocation data, solar angles and visible calibration coefficients
ATS_NR__2P	GST	• Full resolution nadir-only and dual-view SST over sea • Full resolution 11 µm, BT and Normalised Difference Vegetation Index (NDVI) over land • Product quality data, geolocation data and solar angles
ATS_AR__2P	AST	• Spatially averaged ocean, land and cloud parameters • Spatially averaged top of atmosphere BT/reflectance
ATS_MET_2P	Meteo Product	• SST and averaged BT for all clear sea pixels, 10 arc min cell, for Meteo users
ATS_AST_BP	Browse Product	• 3 band colour composite browse image derived from L1b product. 4 km x 4 km sampling.

Table 5-1: Summary of AATSR data products

AATSR was designed primarily to measure sea surface temperature, precisely and accurately. The main aim of the validation programme is, therefore, to assess whether this is being achieved through validation of the Level 2 ATS_NR_2P, ATS_AR_2P and Meteo products. Examination of the BT's in the Level 1b product will be an inherent part of this process.

Validation of the visible channels in the Level 1b product is also important, and is being carried out using land and cloud targets. Also over land, an AATSR LST retrieval is being prototyped for inclusion in the Level 2 products. This prototype is being validated before a decision is made as to whether to produce it operationally.

The browse product is intended to provide 3 band colour composite, quick-look images at coarse resolution. Derived from the L1b product, it is not covered specifically by validation activities, although will be examined as part of the algorithm verification exercise.

6 AATSR Validation Organisation

As AATSR is an Announcement of Opportunity Instrument, the DEFRA is responsible for its calibration and validation throughout the mission. As part of this responsibility, an AATSR validation scientist (VS) has been appointed. The role of the VS is to ensure that the objectives outlined in Section 4 are achieved. The VS coordinates and manages the validation programme for AATSR, ensuring validation data are collected and analysed in a timely manner. The VS acts as a single point of contact for reporting the progress/results of the validation programme on behalf of the AATSR team and DEFRA.

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

The Leicester Contacts are:

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6.1 The MERIS and AATSR Validation Team (MAVT)

During the commissioning phase, Guido Levrini of ESA ESTEC coordinated the cal/val programme. As the mission has moved into Phase E, responsibility for the mission has moved from ESTEC to ESRIN, and Pascal Lecomte has taken over responsibility for the validation programme (Figure 6.1-1).

AATSR validation will still be part of the MERIS and AATSR validation team (MAVT), coordinated Evert Attema at ESA ESTEC, helped by Paul Snoeij (Figure 6.1-3).

In addition to a validation team, there will also be an AATSR Product Quality Working Group (Figure 6.1-2) led by ESRIN, to monitor data quality from an operational point of view. The way this group interfaces with the validation team is described in Section 14.

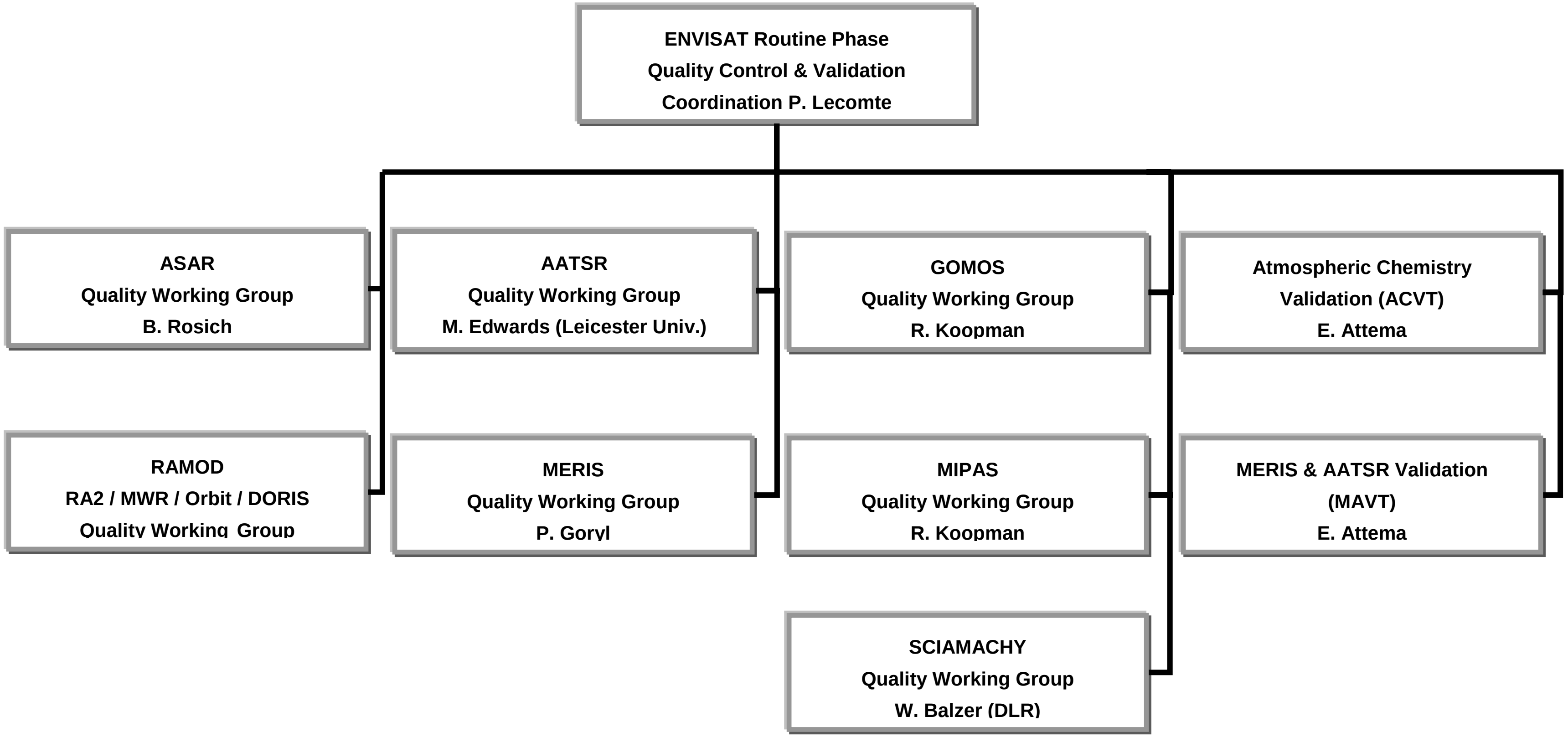

Figure 6.1-1 Organisation of the Envisat Cal/Val Programme

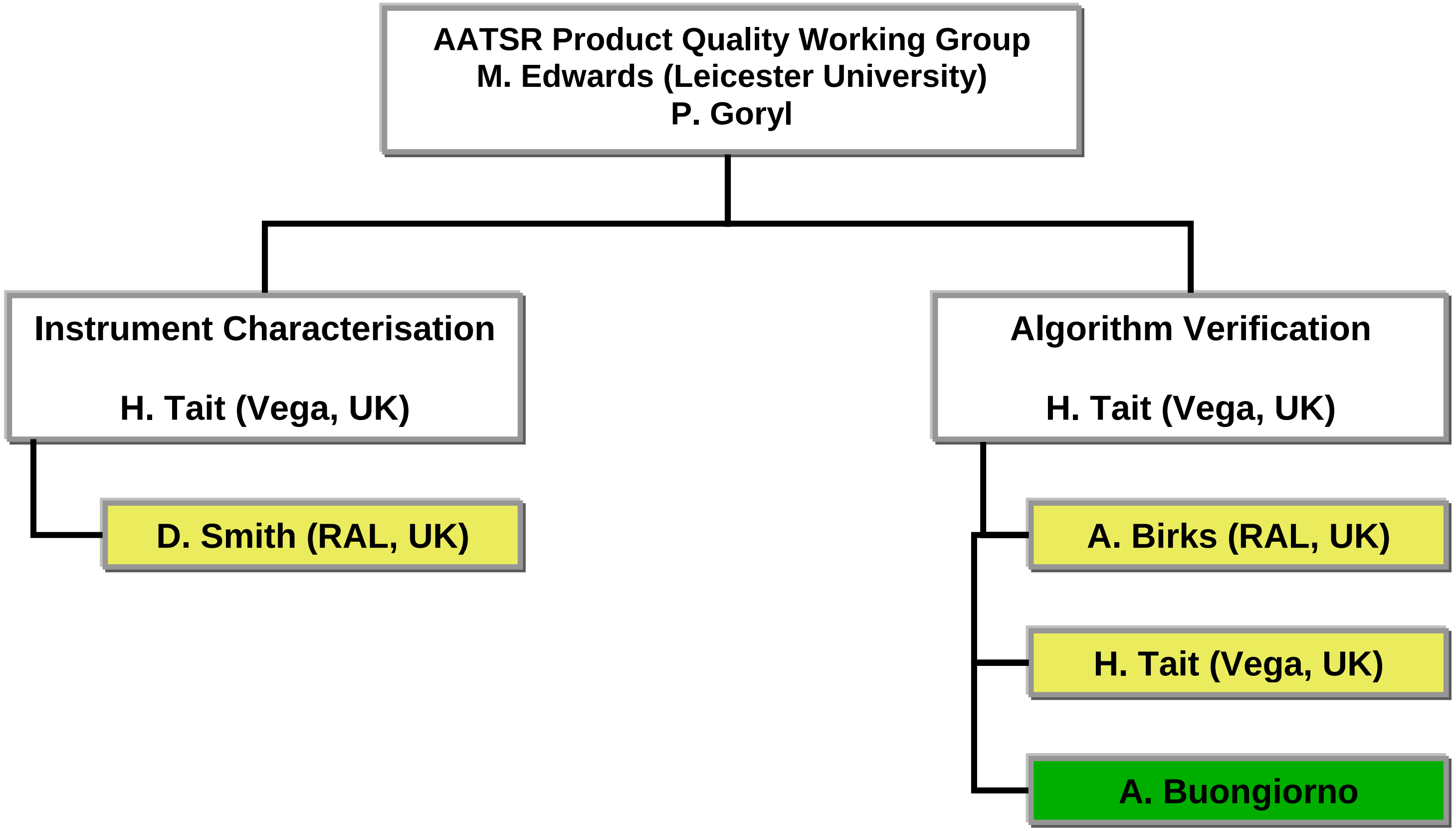

Figure 6.1-2 Organisation of the AATSR Quality Working Group (membership TBC)

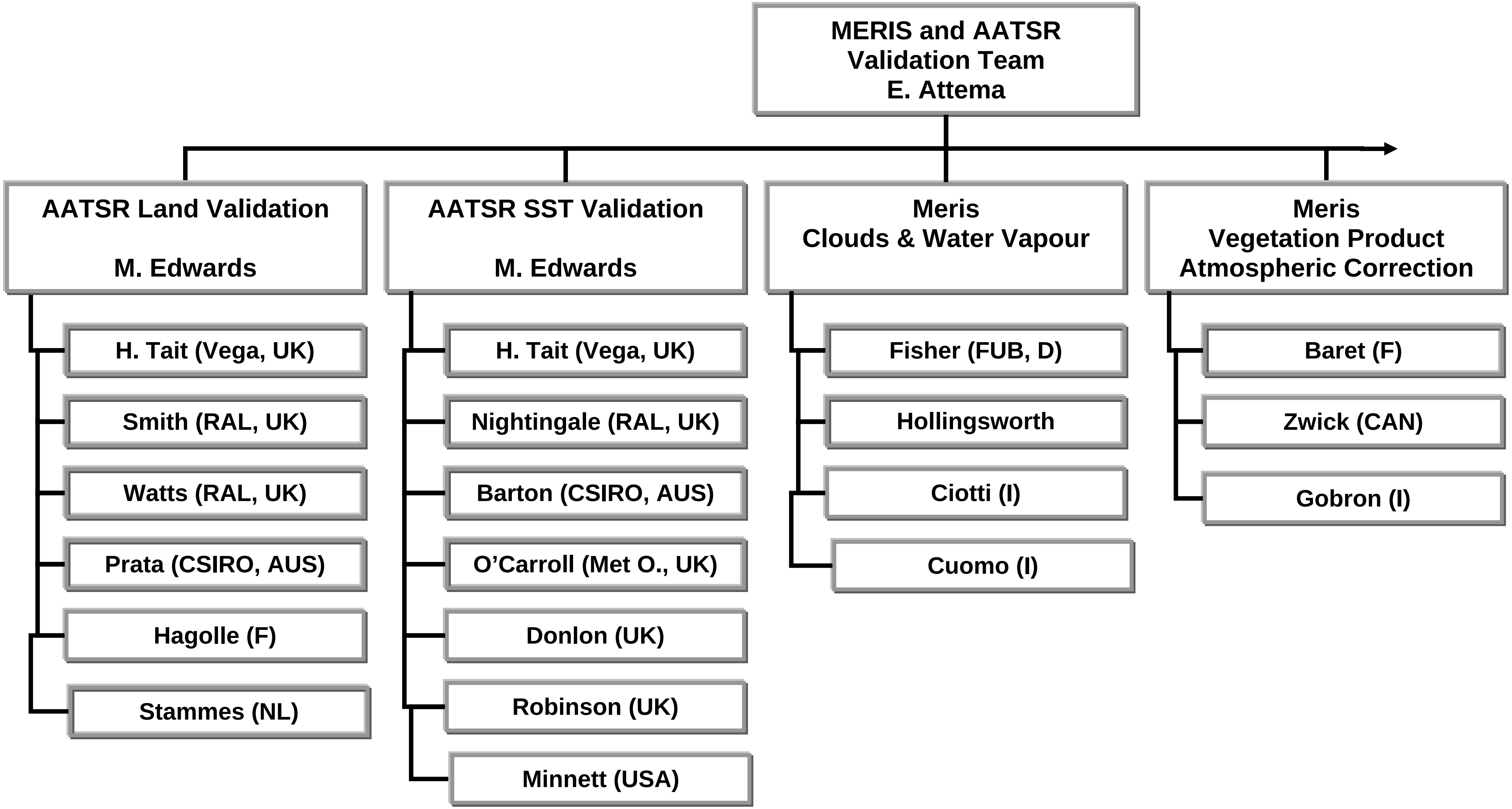

Figure 6.1-3: AATSR validation within the MAVT

7 Calibration

AATSR is a self-calibrating instrument. It has an on-board calibration system, which involves the use of two specially designed and highly stable blackbody reference targets (for the thermal channels), and a diffusely reflecting target that is illuminated once per orbit (for the visible and NIR channels). Furthermore the instrument calibration was verified in ground tests. A number of activities were carried out post-launch to check and characterise the AATSR sensor. These are described in detail in the AATSR Commissioning Report (PO-RP-RAL-AT-0511). AATSR Commissioning was completed on 16th September 2002.

8 Algorithm Verification

Algorithm verification by Andrew Birks of the Rutherford Appleton Laboratory, under an Expert Support Laboratory (ESL) contract to ESA, was started in the Commissioning phase and will continue into Phase E.

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8.1 Methodology

Algorithm verification is distinct from instrument commissioning (as described in AD3). Applying to all processed AATSR products, specific objectives of the activity include:

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

It will encompass a variety of different tests including:

Format Verification

Done independently for each product type, it will be verified that:

- MPH is present and has the expected size;
- SPH is present and has the expected size;
- All ADS and MDS types as specified in the IODD are present;
- SPH contains one DSD corresponding to each data set present;
- SPH contains all required reference and spare DSDs;
- Total product size is consistent with the sum of its component data sets, as defined by the Data Set Descriptors;
- Specified MPH field contents have realistic magnitudes;
- Specified SPH field contents have realistic magnitudes.

Content Verification

The contents of the products will be verified. This will include checking the annotation data sets, geolocation and regridding, radiometric checks, and cloud flagging.

More specific details of the tests used for the different products are given in Table 8-1.

Data from AATSR will be compared to ATSR-2, if possible. Time differences between the two instruments will mean that it will not be possible to check all quantities using this method (e.g. cloud flags).

Product	Test Case #	Test
Level 1b	1	GBTR Format verification
	2	ADS #7 (VISCAL) verification
	3	ADS #3 (Pixel Latitude/Longitude) verification
	4	ADS #4 (scan pixel x and y) verification
	5	Solar and viewing angle verification
	6	Scan and pixel number verification
	7	Image plane consistency
	8	Product confidence words
	9	Land/sea flags
	10	Cloud flags
	11	SQUADS verification
	15	GBTR comparison with ATSR-2 data
Browse	12	Browse product format verification
	13	Browse product ADS
	14	Browse product inspection
Level 2 & METEO	21	GSST Format verification
	22	Level 2 ADS
	23	Level 2 Image data
	24	Level 2 SQUADS verification
	25	AST format verification
	26	AST datasets
	27	ABT datasets
	28	METEO product format verification
	29	METEO product dataset
	30	Level 2 image comparison with ATSR-2 data

Table 8-1: Algorithm Verification Tests[1]

The following level 1 processes cannot be verified directly by inspection of the products:

- Telemetry data unpacking
- Infrared calibration coefficients
- Interpolation of image pixel geolocation

To address these issues, specific breakpoints will be requested in the OP. Additional breakpoints may also be requested if higher level tests show a problem requiring more detailed investigation.

A more detailed description of algorithm verification activities can be found in the AATSR Algorithm Verification Plan (AD 11). This document gives details of test objectives, test data, test procedures, test tools, expected test results or pass/fail criteria, and suggestions for corrective action in case of test failure (e.g. detailed breakpoint analysis).

8.2 Reporting

The results of algorithm verification will be reported to ESA on a monthly basis throughout the period of algorithm verification activities. These reports will also be sent to the VS. A. Birks will participate in the validation loop as required.

[1] These tests may change slightly as algorithm verification test cases continue to evolve.

8.3 Activities during the initial validation phase

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

Birks, A.R., 2002, Algorithm verification for AATSR. ESA special publication 520 (written for the Calibration Review).

Birks, A.R., 2003, Algorithm Verification for AATSR: Level 2 Verification. ESA special Publications 531 (written for the Validation Workshop).

8.4 Algorithm verification during phase E

A subset of algorithm verification tasks will be repeated regularly throughout Phase E for long term product quality monitoring. These tasks are TBD.

9 Validation of Level 2 SST Products

As already discussed, AATSR was designed to measure SST, precisely and accurately. The main aim of the validation programme, therefore, is to assess whether this is being achieved through validation of the Level 2 Gridded Surface Temperature Product, and the Spatially Averaged Surface Temperature Product.
The validation of SST can be done through the use of: -

- Global datasets: Comparison with SST analysis fields, and the systematic review of buoy data.
- Regular cruise (autonomous) instruments.
- Campaign instruments.

Measurements taken under these three headings vary in their frequency, global distribution and accuracy. Figure 9-1 details the PI's leading different projects involved in the three levels of SST validation. Ian Barton of CSIRO is listed several times as he the contact point for all Australian projects. The administrative number of the activity is also listed.

PI's involved in validating SST will validate the SST products, GST and AST. Many have also requested the Level 1b products containing TOA brightness temperatures/reflectance. This will give them the values from which SST has been calculated, and allow assessment of surface conditions and the SST retrieval. The Level 1b product is provided to PI's for anomaly investigations, rather than the derivation and application of new SST retrievals.

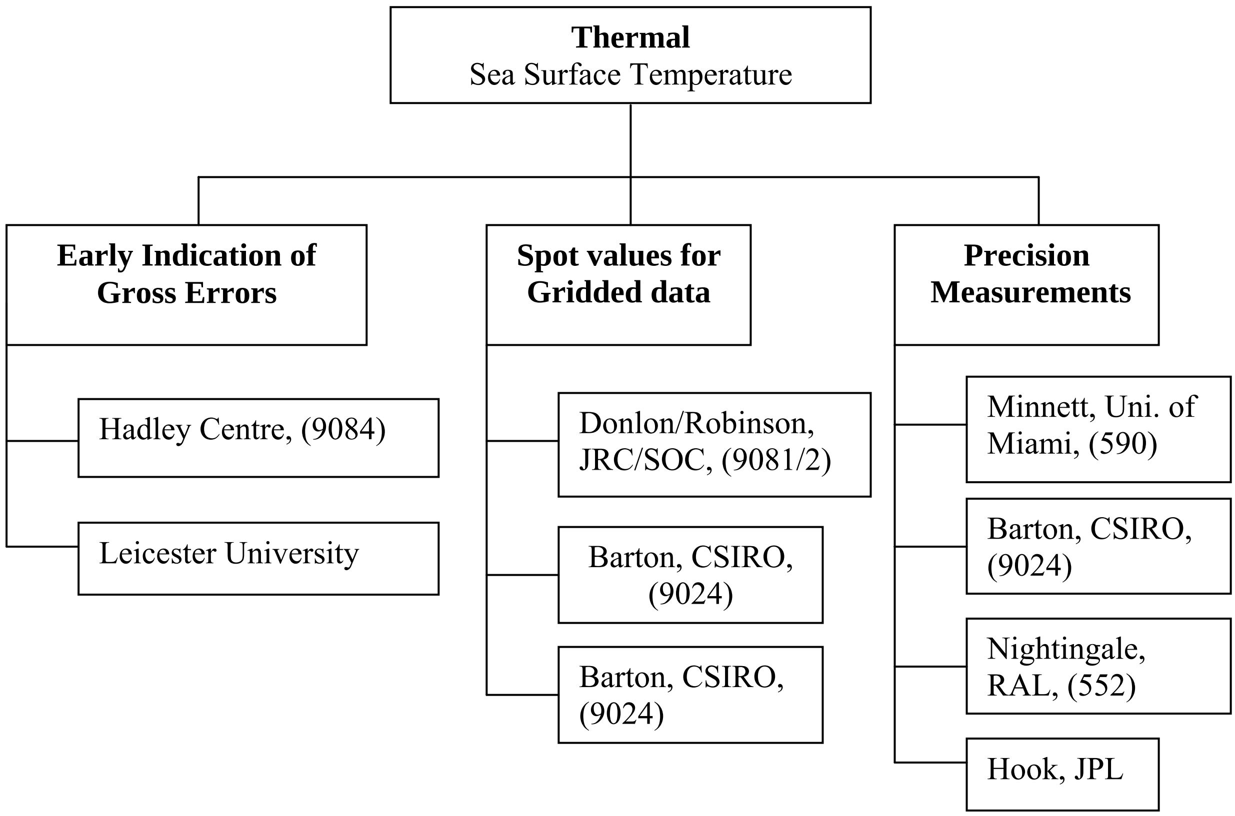

Figure 9-1: Levels of Validation for validating AATSR SST data products, and the PI's involved in each activity.

9.1 Level 1: Global Buoy Comparison including early indication of gross errors in AST data

Many of the early errors in SSTs produced from ATSR-1 and ATSR-2 data were detected using systematic comparisons with buoy data and SST analysis fields. This is a good method of detecting gross errors in SST at an early stage, and is advantageous in that it can be carried out at a global scale and without field data collection campaigns.

9.1.1 Derivation of bulk SST from AATSR SST, and comparison to model SST's and buoy data, Met Office/Hadley Centre (9084)

The Met Office have been validating the AATSR METEO product since its availability on the 19th August 2002. Their validation work will continue throughout Phase E.

The key staff involved in the activity are: -

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9.1.1.1 Methodology

The Met Office derive bulk SST from the AATSR observed skin SST, using surface wind and fluxes of heat and momentum from operational global NWP analyses. A skin to bulk correction is applied to the near real time AST product.

It is planned, after careful monitoring, to assimilate the derived bulk SSTs into the new HadISST analysis scheme, along with in situ data, using Laplacian techniques and optimal interpolation, similar to the way in which AVHRR MCSSTs are assimilated. The HadISST

[2] L. Horrocks will work on the AATSR project until Easter 2003.
[3] A. O'Carroll will return to work on the AATSR project in the Spring 2003.

analyses are globally complete SST and sea-ice monthly fields at 1° spatial resolution, available one month behind time.

The steps of the processing chain are:

1. Retrieve and decode AATSR near-real-time BUFR data
2. Compute skin SST's (10' × 10') from brightness temperatures
3. Combine (10' × 10') AST data into 0.5° × 0.5° data (if required)
4. Retrieve and interpolate (in space and time) the fluxes to drive the models of the skin effect and diurnal thermocline, and other fields required for quality control. This can be done over the full instrument swath.
5. Quality control incoming AATSR AST data.
6. Calculate value of delta-T (skin) from parameterisation of skin effect using model fluxes.
7. Calculate value of delta-T (sub-skin to 1m depth) from model of diurnal thermocline, using history of fluxes to set a diurnal thermocline flag if computations show a significant thermocline is likely.
8. Quality control output of skin and thermocline models.
9. Write out record of bulk SST, skin SST, latitude, longitude, time, across-track distance, delta-T's, quality control information, heat fluxes, brightness temperatures.
10. Retrieve buoy data and match in space and time with AATSR data. Produce NRT matchup file.
11. Retrieve offline buoy data (e.g. TOA array) and match with AATSR swath. Produce offline matchup file.

In addition to processing AATSR data in near real time, the same chain can also be used for processing ATSR-1/2 data, offline. The flexibility of using fluxes from an NWP model other than the Met Office's will be included (e.g. ECMWF reanalysis fields).

The METEO product provides the Met Office with both SST values and spatially averaged brightness temperatures (BT) for all clear sea pixels, in 10 arc minute cells. The processing and data analysis system set up by the Met Office is designed to be totally flexible. It takes the AATSR BT values, applies SST coefficients and thus generates SST values. Whilst the Met Office may generate and test new coefficients, they confirm that for validation purposes, the 'official' SST coefficients will be used.

The Met Office would like to carry out cross comparisons between ATSR-2 and AATSR, but

9.1.1.2 Validation results and deliverables

Results from validation activities at the Met Office are available in different ways. There is a password protected Met Office website at: -
http://www.metoffice.com/research/nwp/satellite/index.html.

This gives:

- Daily maps showing bulk/skin SST, skin delta T, thermocline, NWP fluxes and error estimations.
- Every 5 days: Time series of regional/global means (and standard deviations) of the difference between AATSR SSTs (both skin and bulk), and the MohSST pentads (in situ

observations at 5° spatial resolution). The purpose of this comparison at the pentad resolution is to highlight sudden gross changes in the instrument performance.
- Every 5 days and monthly: Global maps of the differences between AATSR SST's and the MohSST pentads (as above).
- Monthly: Monthly mean maps of the bias/standard deviation of the difference between AATSR skin/bulk SST's and HadISST (an SST dataset compiled from in-situ and AVHRR data, at 1° spatial resolution). This will be a much finer comparison than the weekly checks, and will detect not only instrument problems but also levels of accuracy and any regional anomalies. Statistics will be compiled with a lag of one month since the preliminary NRT HadiSST datasets need to be compiled by the Hadley Centre first.
- Monthly: Match-up datasets of skin/bulk SST's and drifting/fixed buoy SST's. A subset of these buoy matchups will be uploaded every month to the NILU database.
- Monthly: Summary reports outlining validation activities and significant results.

9.1.1.3 Geographical Location

The Met Office will validate AATSR data over the oceans on a global scale subject to availability of global data from the satellite (i.e. no blind orbits), and the inevitable limitations of using in situ observations.

9.1.1.4 Validation Activities

9.1.1.4.1 Up to Validation Workshop

The Met Office were the first validation PI's to receive AATSR data. From the 19th August to the Validation Workshop, daily processing of the METEO product was carried out with comparisons made on a global scale to SST analysis fields and in situ buoy data.

9.1.1.4.2 Validation in Phase E

The Met Office will continue to validate AATSR data throughout Phase E.

9.1.1.5 Data Requirements

The Hadley Centre requires the ENVISAT AATSR Meteo Product (ATS_MET_2P) in Near Real Time (within 24 hours of measurement time). All orbits are required, and will be ftp'd from ESA.

9.1.2 Global comparisons of AATSR SST with data from other satellite sensors

Up to the Validation Workshop, the University of Leicester compared SST data from AATSR with SST data from MODIS, ECMWF and TMI. Comparisons of AATSR SST on a global scale with SST data from a variety of sensors will continue into Phase E.

The key staff involved in this activity are:-

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9.1.2.1 Methodology

The University of Leicester plans to compare AATSR SST data with data from ATSR-2, MODIS, AVHRR, TMI and ECMWF analysis over time. The comparisons between datasets are made of monthly mean SST data at half-degree resolution. Monthly mean datasets for AATSR data are calculated as the mean dual view SST from all available data (day and night) from the spatially averaged product for a given month. Outputs from the comparisons include global and regional (as specified by the user) scale difference images, statistics and temperature difference distribution plots. Given a time series of data, changes in temperature difference between datasets can also be plotted and analysed.

9.1.2.2 Geographic Location

The comparisons are performed on a global scale initially. Once an area of interest has been identified, this area can be isolated and extracted for a more detailed analysis.

9.1.2.3 Validation Activities

9.1.2.3.1 Up to Validation Workshop

Up to the Validation Workshop, comparisons were made between AATSR data and MODIS, TMI and ECMWF data for September 2002. These results were presented at the Validation Workshop.

9.1.2.3.2 Validation in Phase E

Comparisons will continue into Phase E.

9.1.2.4 Data Requirements

The University of Leicester receives all L2 AATSR data on CD from the UK PAC. It is expected that this service will continue throughout Phase E.

9.2 Level 2: Spot values for validating GST data

Validation of AATSR data using in situ data from autonomous instruments will continue in Phase E.

9.2.1 Infrared Sea surface skin temperature Autonomous Radiometer (ISAR5C) system (9082)

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Co-Investigators:

Mike Reynolds, BNL
Dr Tim Nightingale, RAL

9.2.1.1 Instrumentation

ISAR5C is a precision, autonomous, self-calibrating infrared radiometer, capable of measuring in situ sea surface temperature (SSST) accurate to ± 0.1K rmse, as demonstrated at the recent CEOS-RSMAS radiometer intercalibration exercise (see Figure 9.2.1.1-1). The ISAR5C radiometer uses two precision calibration black body (BB) cavities to maintain the radiance calibration of a solid state infrared detector having a spectral window of 9.6-11.5µm. All ISAR5C target views are made using a single route optical path via a protective scan drum arrangement that allows the target view to be accurately positioned over a range of 180°. The BB apertures are completely sealed from direct water ingress using a patent pending shutter mechanism triggered by an optical rain sensor that completely seals the ISAR5C from the external environment. This is important in order to protect the instrument on deployments of up to 3 months. The high quality rain sensor is also used to determine the position of the ISAR5C in relation to recent rain events where cooler freshwater would be expected at the sea surface, further complicating the relationship between the SST at depth and that observed by AATSR.

Figure 9.2.1.1-1 The Infrared Autonomous SST Radiometer (ISAR5C) shown together with the optical rain gauge. The rain gauge is used to control the opening/closing of a shutter system that seals the instrument from rain and sea spray during bad weather.

The ISAR5C system has been designed from the outset to provide a total solution to the needs of satellite validation work. It has a dedicated fully configurable RS-485 port that can be used to connect other sensors required to place the radiometer measurements into an ocean-atmosphere context. For the validation of AATSR, the ISAR5C system has been configured to log solar radiation, air temperature and humidity. Additional supporting data collected independently of the ISAR5C system include bulk SST determined from a SBE-48 hull mounted (internal) sensor and wind vectors from a Gill Windmaster 3 axis sonic anenometer. The maximum deployment of an ISAR5C instrument is 3 months although experience suggests that the ISAR5C, like any other oceanographic instrument, should be thoroughly checked at 1-month intervals for problems.

ISAR5C was designed by Craig Donlon and developed in conjunction with Southampton University. The building and deploying of the instrument in the initial phase was funded by DEFRA and Southampton University.

9.2.1.2 Methodology

Figure 9.2.1.2-1 shows the structure of the ISAR project and the personnel involved.

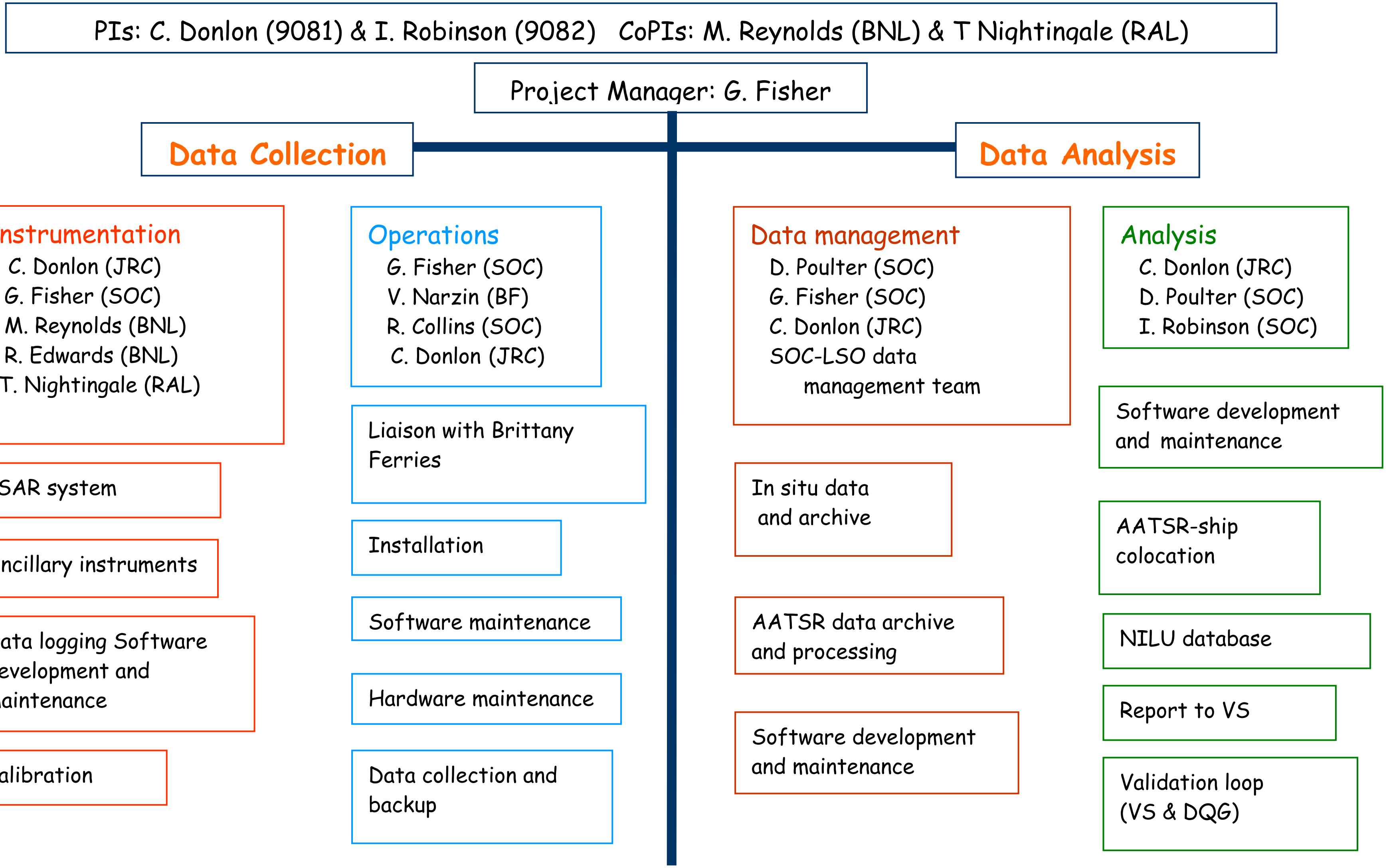

Figure 9.2.1.2-1: Structure of the ISAR project

The methodology can be divided into the in situ data collection and the co-location with AATSR data.

In situ data

- As the ferry continues normal operating duties, ISAR5C provides measurements of SST at 3-minute intervals. The SST data is derived as an integrated average over a 1 minute period and includes full correction for sky reflections at the sea surface, calibration and ancillary engineering data.
- An automatic CDWR backup of each day’s data is made every night. Complete data download will depend on access to the ship and may incur a delay of up to 3 months depending on vessel operations.
- The quality of the data is maintained via mandatory pre and post deployment calibrations (using a CASOTS-BB and a NIST standards traceable thermistor, maintained at SOC specifically for this purpose), and by periodic cross deployment with the SISTeR instrument. Each ISAR5C will undergo a complete service and parts replacement according to a maintenance schedule following every deployment.

Co-location with AATSR data

- AATSR data are extracted and overlain with the ship track
- All AATSR data within ± 1 hour of ship position and within ± 25km is automatically extracted.
- A detailed analysis of contemporaneous ship and AATSR data will be performed on a case-by-case basis at the highest spatial and temporal resolution possible, taking into consideration all available data (e.g. visual observations, other satellite data (RA2), ship logs etc).
- The match-up data and monthly reports are sent to the VS, and enter the validation loop. Correlative measurements will be entered into the NILU database.

9.2.1.3 Geographic Location

The geographic location covered by these validation activities is described in 9.2.1.4.

9.2.1.4 Validation Activities

9.2.1.4.1 Up to Validation Workshop

During the initial validation phase, the ISAR5C has been deployed on two ferries, the Val de Loire and the Pride of Bilboa.

Val de Loire

The ISAR5C was deployed on the Brittany Ferry, the Val de Loire, from May 15th to June 26th 2002 (see Figure 9.2.1.3-1).

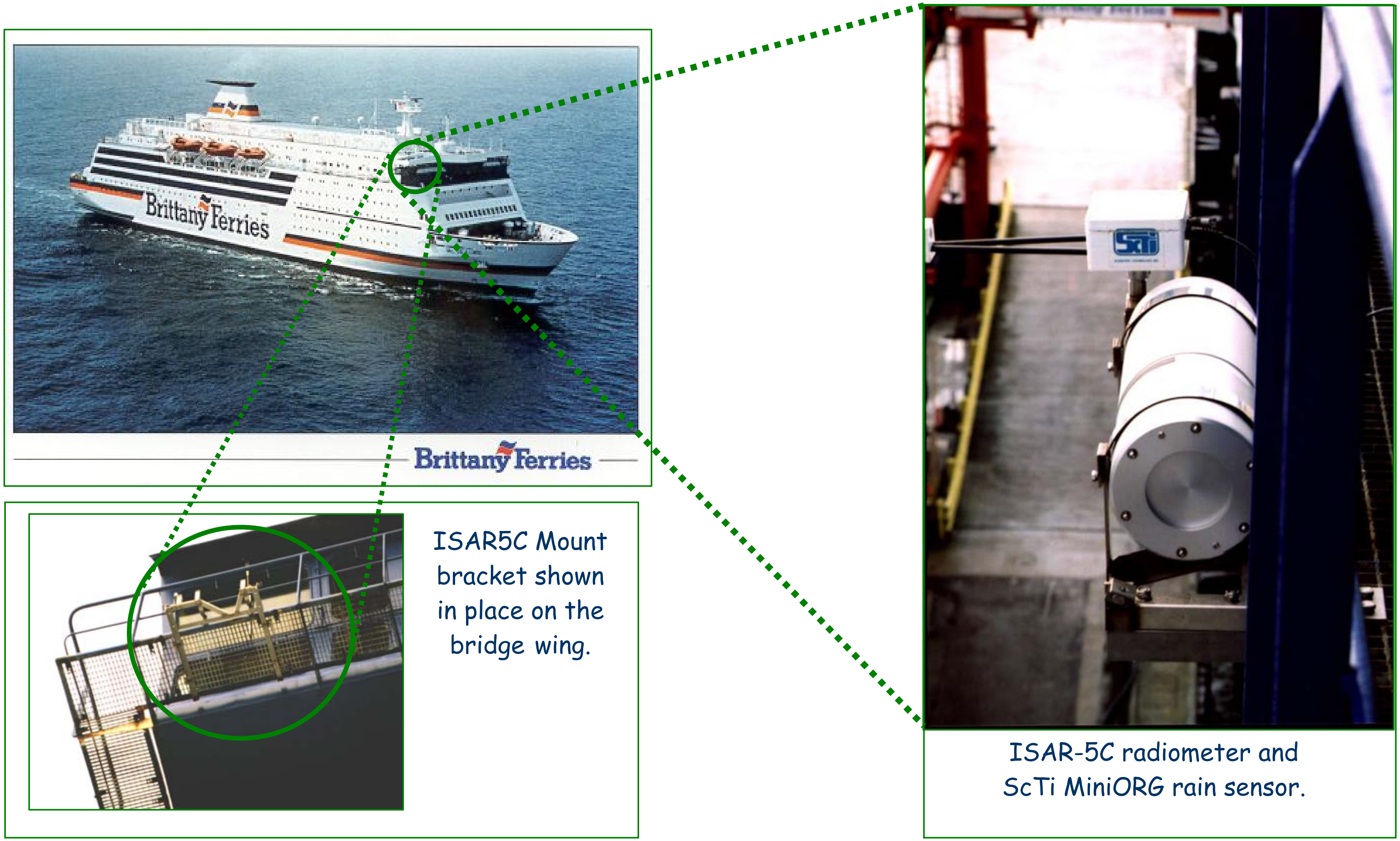

Figure 9.2.1.3-1: Deployment of the ISAR5C on the Brittany Ferry, the Val de Loire

Figure 9.2.1.3-2 shows the route of the ferry plus a crude indication of validation points attained. Validation indicators are defined using sky brightness temperatures (BTsky) from the ISAR, as:-

- Good: clear sky (BTsky < 200 K)
- Fair: broken cloud (200 K< BTsky < 260 K)
- No chance: cloudy sky (BTsky > 260 K)

SST data obtained from the ISAR during this period is shown in Figure 9.2.1.3-3. Using the validation indicators, it is estimated that there were 37 good and 42 fair validation chances during the deployment.

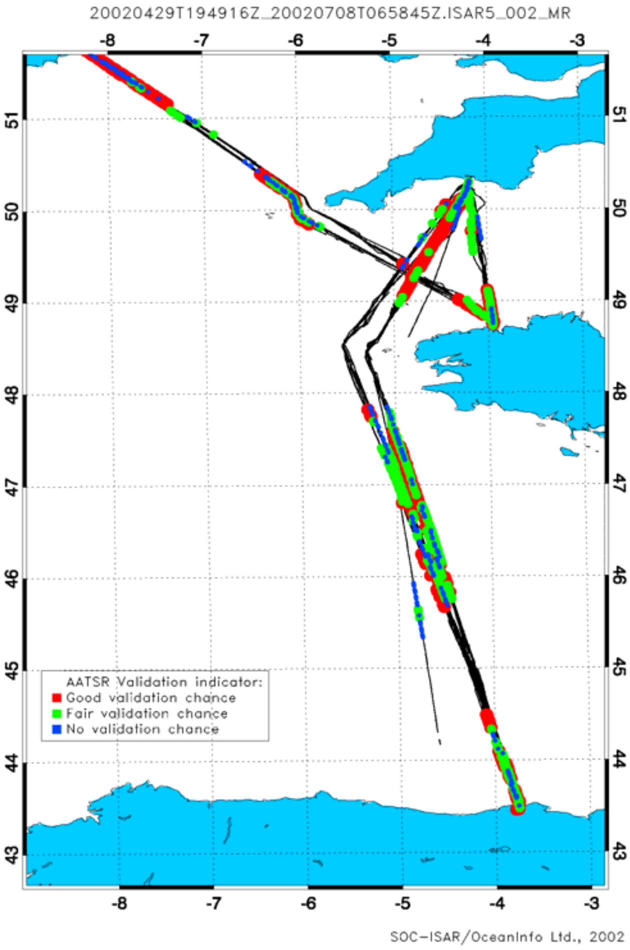

Figure 9.2.1.3-2: Route of the deployment of the ISAR5C on the Val de Loire Ferry, plus an indicator of validation chance

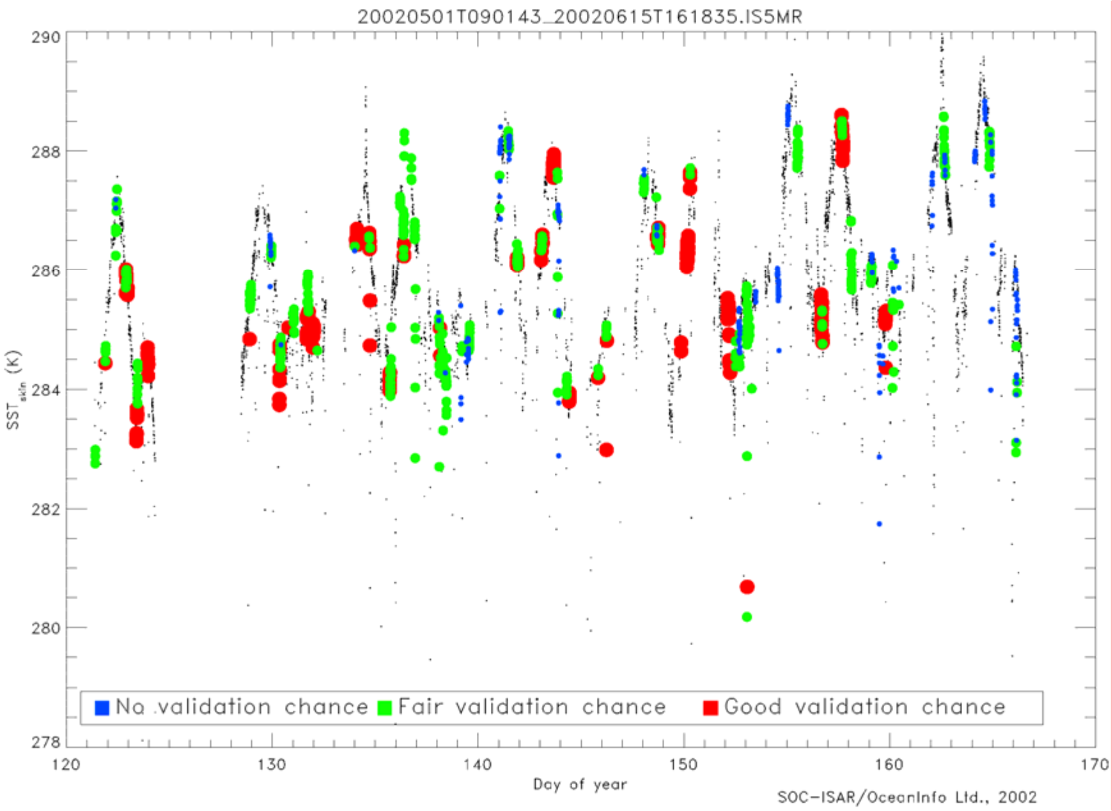

Figure 9.2.1.3-3: SST data collected using ISAR5C during the Val de Loire deployment

The ferry route is defined by the coordinates:

51N, 0W
49.6N, 1E
49N, 1W
48.4N, 4.5W
46.5N, 1.2W
43.4N, 1.2W
43.4N, 5W
51.5N, 9.5W
52N, 7.5W
50N, 5.7W
50.4N, 4.2W
51N, 0W

Pride of Bilboa

Due to operating difficulties on the Val de Loire, the ISAR5C was transferred to the P & O ferry, the Pride of Bilboa on August 16th 2002. This ferry follows a similar cruise track to the Val de Loire. Deployment on the Pride of Bilboa has the advantage in that Southampton Oceanography Centre runs a 'FerryBox' experiment from this ship. The Ferrybox experiment provides near-real-time underway data via satellite link from a thermosalinograph and flourimeter. The ISAR will be interfaced with this system in January 2003.

Installation of the ISAR5C on the Pride of Bilboa is illustrated in Figure 9.2.1.3-4

Unfortunately due to poor weather conditions and technical difficulties, no validation points have been obtained to date on this deployment to date (see Figures 9.2.1.3-5 and 9.2.1.3-6).

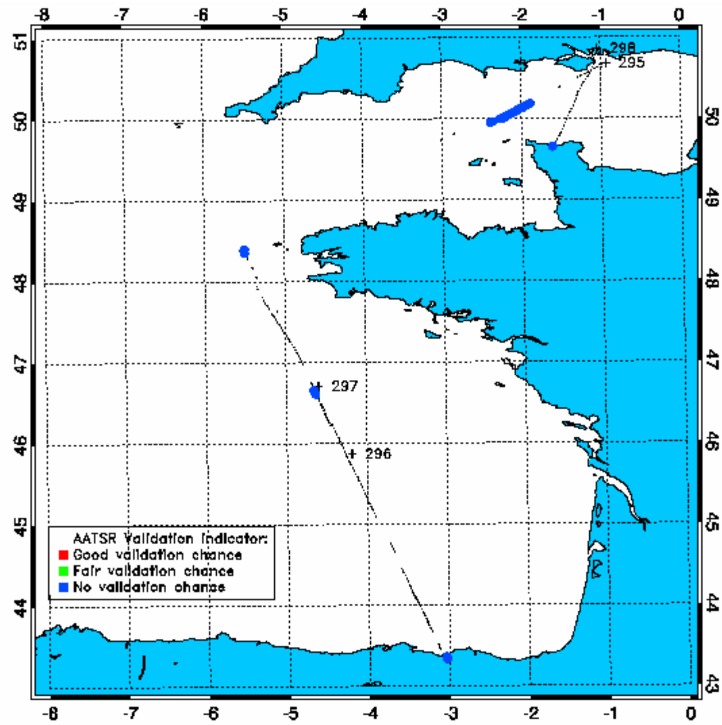

Figure 9.2.1.3-5: Deployment of the ISAR on the Pride of Bilboa

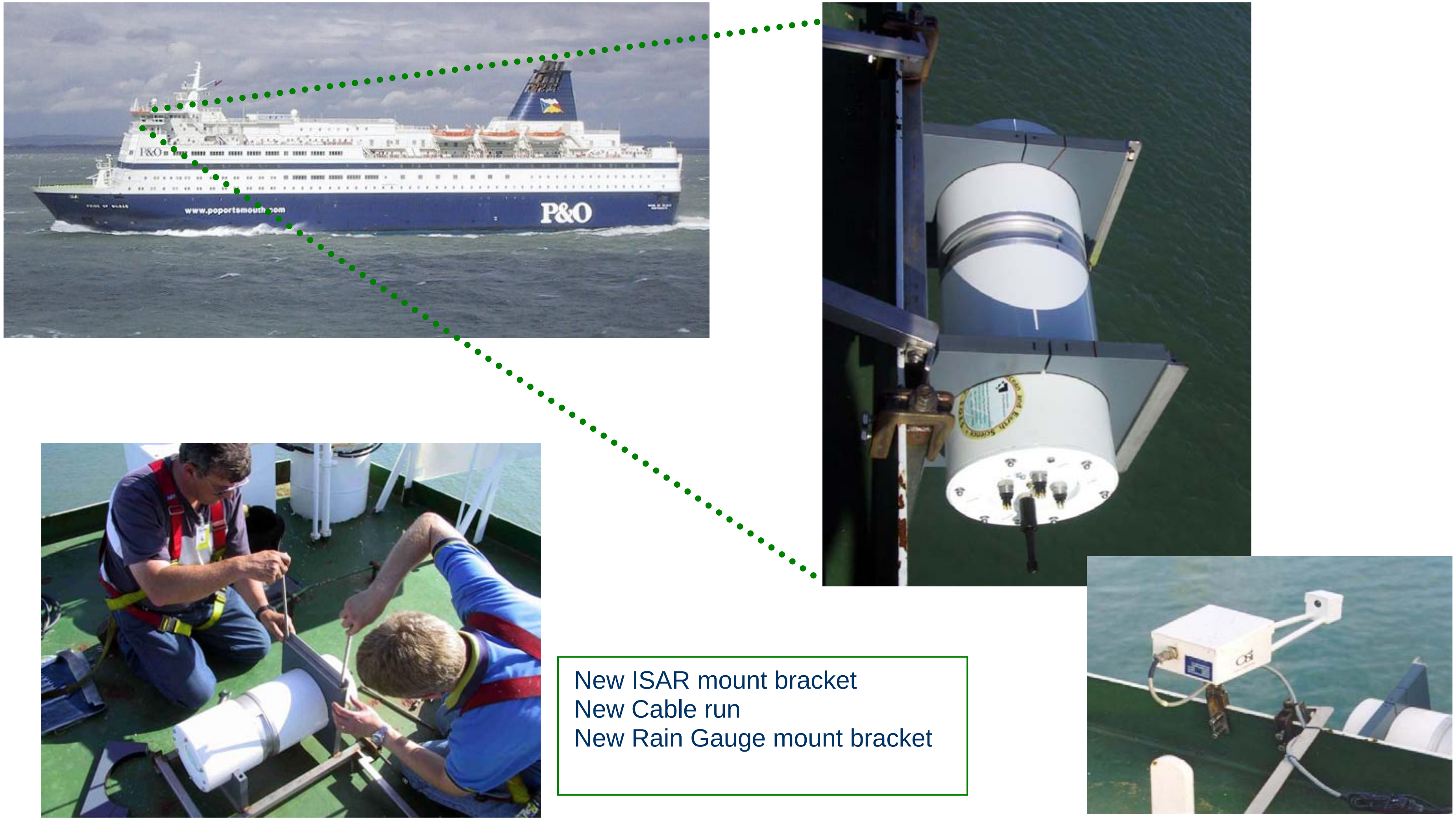

Figure 9.2.1.3-4: Installation on the Pride of Bilboa

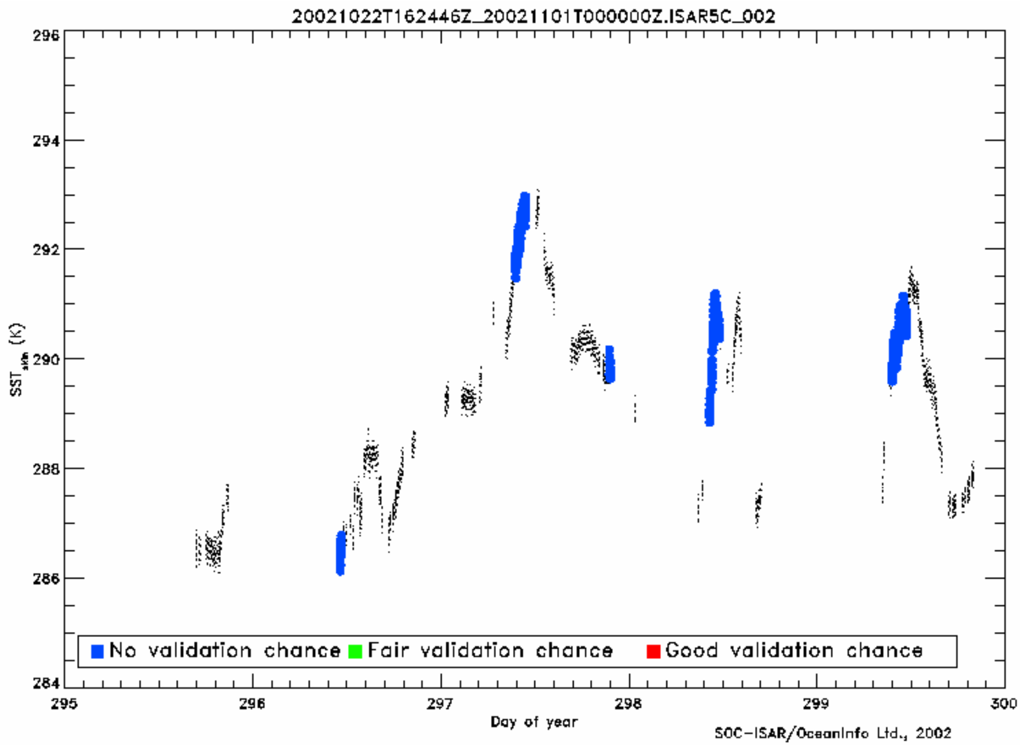

Figure 9.2.1.3-6 Validation points obtained from the Pride of Bilboa deployment

9.2.1.4.2 Phase E validation activities

Although there is currently no external funding for the ISAR project in Phase E, Southampton will continue to operate the ISAR5C instrument on the Pride of Bilboa ferry until funding runs out (currently mid 2003). Beyond this time, there is a possibility that the ISAR will operate under the NOPP, on the Falstaff ship (TBD). This is a car carrier operated by Wallenius Lines, between Europe and the United States. Figure 9.2.1.4-1 shows the Falstaff route.

ISAR will also take part in a planned experiment in the North Adriatic in June 2003.

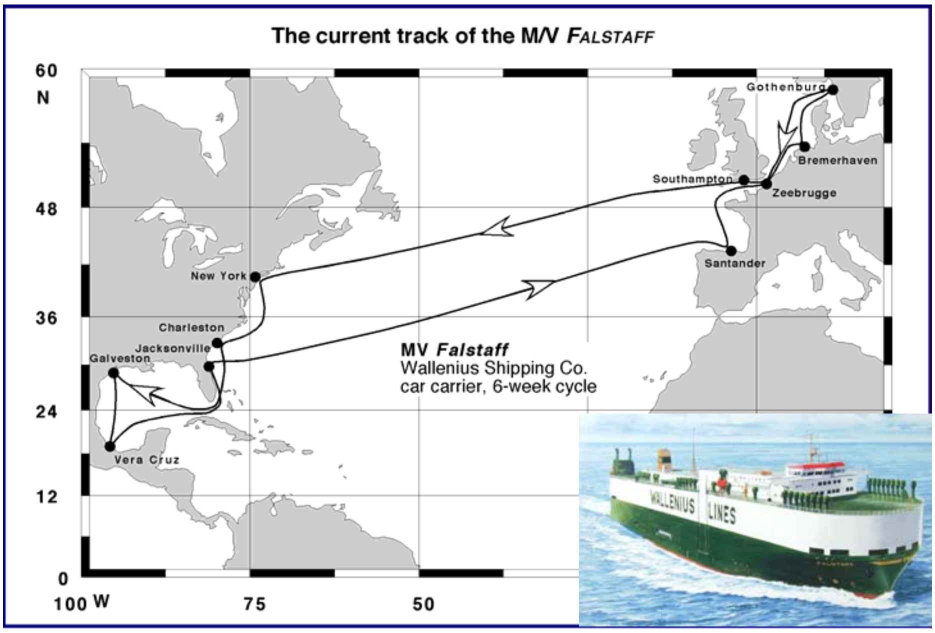

Figure 9.2.1.4-1 Route of the Falstaff Ferry, which may accommodate the ISAR5C (TBC)

9.2.1.5 Data Requirements

Throughout Phase E, the ISAR project team will continue to require L2 and L1b AATSR data over areas of interest. They expect to continue receiving CD's from the UK-PAC containing all AATSR L2 data. Specific scenes of L1b data will be ordered as and when necessary.

In addition, the team requires specific radar altimeter data (RA-2_WWV_2P and RA2_GDR_2P products). These will be ordered as and when necessary.

During Phase E, data should be sent to both Professor Ian Robinson at Southampton Oceanography Centre and Dr Craig Donlon at JRC (addresses as above).

9.2.2 The Rottnest Island Ferry in Perth, Barton (9024)

Measurements for validation are being collected by an infrared radiometer, and a bulk SST thermometer, fitted to a passenger ferry that operates on a daily basis between the Perth coast and Rottnest Island, 25km offshore.

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9.2.2.1 Instrumentation

During the initial validation phase, a new radiometer system was been developed for the Perth-Rottnest Island ferry. The system is based on a TASCO radiometer, which is mounted in a housing that allows a view of the water outside the ferry wake in normal operations. The radiometer section can be fully sealed when the ferry is in port allowing fresh water washing of the system. While under way a fan provides a positive pressure within the housing and the air stream expressing from the view port prevents ant water or spray from entering the unit. A GPS system is included for navigation and a platinum resistance thermometer in the cooling water inlet allows a measure of the bulk SST. Downwelling sky radiance is measured at a coastal site to give a correction for clear sky emissivity. The radiometer can be seen attached to the deck above the ferry's bridge in Fig. 1. Within the radiometer housing the TASCO radiometer is mounted in a detachable unit allowing easy replacement and laboratory calibration. The TASCO lenses are susceptible to degradation in a marine environment and are replaced at least once per month. Calibration is undertaken using a portable black body target. This can be done in situ (on the ferry) or in the laboratory.

Figure 9.2.1.1-1 The new Perth radiometer mounted on the ferry "Sea Flyte"

9.2.2.2 Methodology

1 **Instrument installation:** The TASCO radiometer is fitted to the Rottnest Island passenger ferry "Sea Flyte", with a clear beam view of the sea. It samples in the 8 to 12 µm range.

2 **Validation Data Collection:** The ferry travels daily between Hillarys Marina and Rottnest Island (32°S), with different schedules in summer and winter. On a typical daily schedule, the ferry departs at 0900 and 1430 daily, with a travel time to the Island of 40 minutes. On the transect, the datalogger records both TASCO, Bulk SST PRT measurements, and GPS position, at 10-second intervals, and after downloading, 1-km averages are computed along the track.

3 **Data Download:** Once a week or fortnight, the instrumentation is checked and maintained, and data are downloaded.

4 **Satellite data ordering and collection:** Co-incident AATSR will be received

5 **In situ/satellite data matchups:** High resolution (1km) AATSR data contemporaneous with valid TASCO data are required to perform a satisfactory validation study. Matchups between SST measurements collected by the TASCO and cloud free AATSR imagery are made at Marmion.

9.2.2.3 Geographical Location

Validation measurements are being collected in Perth, Australia, along the Hillarys - Rottnest Island transect (25 km). Only daytime data is being collected. This is located at 31.8° S, 115.8°E to 32.0°S, 115.5°E. Figure 9.2.2.3-1 shows a map of the transect along which validation data are collected.

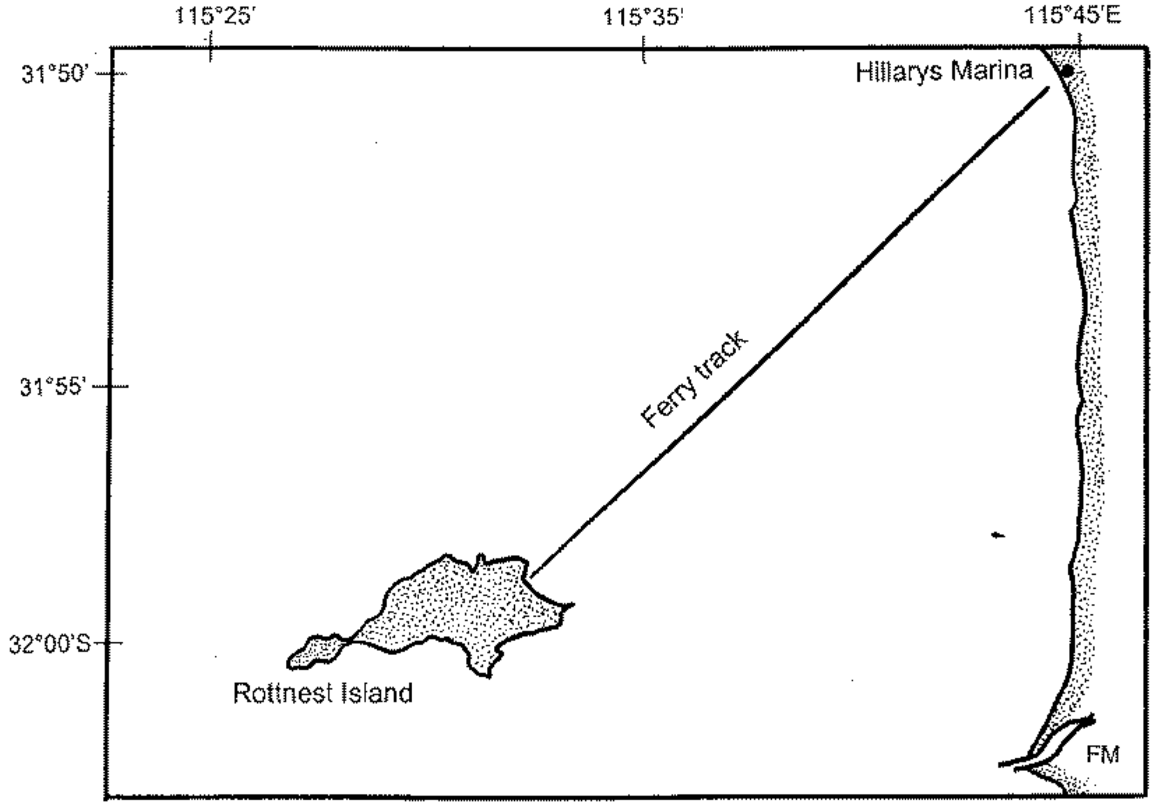

Figure 9.2.2.3-1 Ferry transect along which validation data will be collected with the TASCO radiometer

9.2.2.4 Validation Activities

9.2.2.4.1 Up to Validation Workshop

The new Perth radiometer had some teething problems during the initial validation phase, but radiometric and bulk SST data have been collected since October 10th 2002. These data are currently being compared to satellite-derived SST data.

9.2.2.4.2 In Phase E

The Perth ferry radiometer is planned to operate throughout Phase E. During the austral summer the DAR011 and Perth radiometer will be operated together on the ferry for a short time.

9.2.2.5 Data requirements

Throughout Phase E, the project team will continue to require L2 and L1b AATSR data over the area of interest. They expect to continue receiving CD's from the UK-PAC containing all AATSR L2 data. Specific scenes of L1b data will be ordered as and when necessary.

During Phase E, data should be sent to Dr Ian Barton at CSIRO Marine Research (address as above).

9.2.3 The wave-piercing ferry in Townsville, Barton (9201)

Validation measurements will be collected using an infrared radiometer fitted on a wave-piercing catamaran ferry.

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9.2.3.1 Instrumentation

A new radiometer system has also been developed by the Australian Institute of Marine Science (AIMS) for the Townsville operation. The system incorporates an Everest radiometer and two calibration targets held at ambient temperature and ambient temperature plus 10^{o}C. Bulk SST is measured and an upward looking pyrgeometer is used for the sky correction. During normal operations, the radiometer is installed on the Island Pearl Ferry which operates between Townsville and Kelso reef on the Great Barrier Reef.

The radiometer has also been operated alongside the DAR011 during a 9-day cruise on the RV Lady Basten during June 2002. Excellent agreement was obtained between the two radiometers. The two radiometers are shown mounted on the port-side railing of the RV Lady Basten in Fig. 2.

Figure 9.2.3.1-1 The DAR011 (left) and the AIMS radiometer (right) mounted on the RV Lady Basten

9.2.3.2 Methodology

1. **Instrument installation:** The Everest radiometer is fitted to the bow of the Island Pearl Ferry.
2. **Validation Data Collection:** The Ferry travels from Townsville to Kelso Reef, a distance of 90 km at between 9.00 and 11 am every day, 5 or 6 days a week. On the transect, the radiometer records measurements at 8-14μm wavelengths, at single waveband intervals. The system averages over one minute. A bulk SST measurement, a pyrgeometer output, and local radiosondes give an emissivity correction.
3. **Data Download:** Once a week, the instrumentation is checked and maintained, and data are downloaded daily.
4. **Satellite data ordering and collection:** Coincident AATSR data will be obtained.
5. **In situ/satellite data matchups:** High resolution (1km) AATSR data contemporaneous with valid Everest data are required to perform a satisfactory validation study. Matchups between in situ SST measurements and cloud free AATSR imagery will be made at AIMS.

9.2.3.3 Geographical Location

Validation measurements are being collected on a 90km transect between the Australian coast at Townsville and the Great Barrier Reef. This is at 19.2 S to 18.5 S along 147.0 E. During the austral winter months, this area has an extremely low level of cloud cover, which will ensure that many data coincidences between ship and satellite data occur.

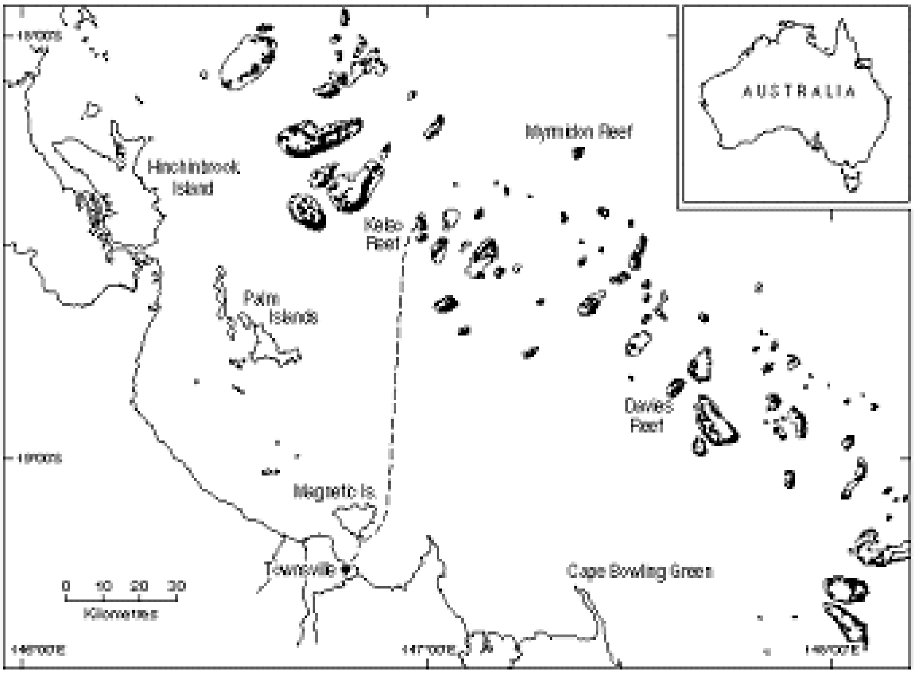

Figure 9.2.3.3-1 Location of the validation activities operating from Townsville to the Great Barrier Reef.

9.2.3.4 Validation Activities

9.2.3.4.1 Up to Validation Workshop

The operation for AATSR validation of the Townsville ferry radiometer has been delayed due to a malfunction in the Everest radiometer which is at the heart of the instrument. The radiometer was however, deployed alongside the DAR011 on one of the Lady Basten cruises and found to operate extremely well, with almost perfect agreement between the two radiometers. When the radiometer is eventually deployed it will provide regular radiometric data for ongoing SST validation during the extended AATSR mission.

9.2.3.4.2 In Phase E

Early in 2003, the DAR011 radiometer will be deployed alongside the new AIMS radiometer on the tourist ferry. This will ensure that the data collected have some consistency, and that the radiometer calibration is accurate.

It is planned to operate the Townsville ferry radiometer for AATSR validation activities throughout Phase E.

9.2.3.5 Data requirements

Throughout Phase E, the project team will continue to require L2 and L1b AATSR data over the area of interest. They expect to continue receiving CD's from the UK-PAC containing all AATSR L2 data. Specific scenes of L1b data will be ordered as and when necessary.

During Phase E, data should be sent to Dr Ian Barton at CSIRO Marine Research (address as above).

9.3 Level 3: Precision Measurements for validating GST data

On the third level, validation is taking place using radiometers specifically designed to take measurements of a high precision. These instruments are generally not autonomous and as a consequence, provide fewer data points and a limited coverage. Data, however, are very accurate, and supplements information given from Level 1 and Level 2 validation activities.

9.3.1 SISTeR, Nightingale (552)

SISTeR is a precision radiometer developed by Dr Tim Nightingale of RAL. It has been used for the validation of ATSR and ATSR-2 data. For more information on SISTeR, see http://www.atsr.rl.ac.uk/validation/, and the references listed below.

Principal Investigator: Dr Tim Nightingale
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Co-Investigators: Dr Chris Mutlow, RAL
Dr Marianne Edwards, University of Leicester
Dr Craig Donlon, JRC

9.3.1.1 Instrumentation

The Scanning Infrared Sea surface Temperature Radiometer, SISTeR, is a compact and flexible, self-calibrating radiometer, specifically designed for research in a maritime environment. It measures approximately 20 x 20 x 40 cm, and weighs about 20kg. SISTeR is shown in Figure 9.3.1.1-1.

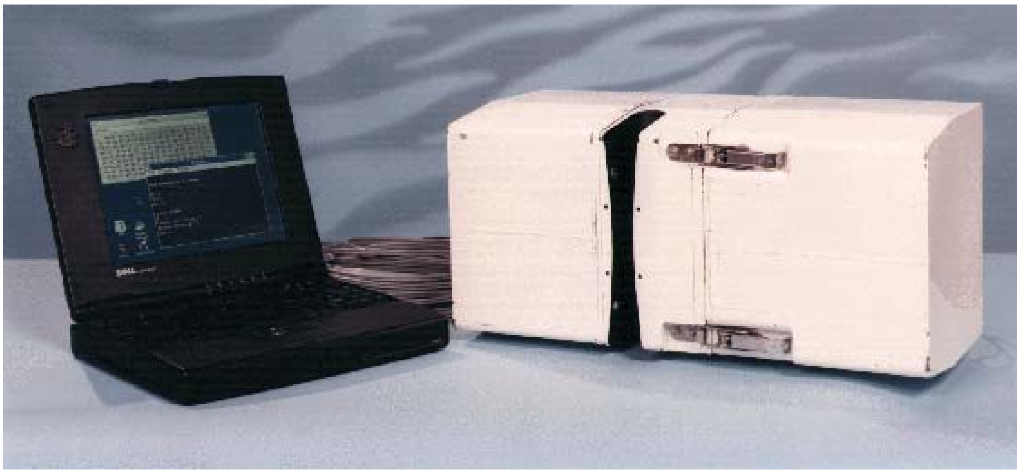

Figure 9.3.1.1-1: The SISTeR radiometer and supporting equipment (taken from http://www.atsr.rl.ac.uk/validation/sister/sis_inst/)

The instrument is divided into three compartments containing the fore-optics, the scan mirror and reference black bodies, a small format PC with signal processing and control electronics. The fore-optics compartment contains a DLATGS pyroelectric detector and preamplifier, mounted onto an assembly containing a concentric 6-position filter wheel and a black rotating chopper. The filter wheel contains three narrow-band filters centred at 3.7µm, 10.8µm and 12.0µm, matching those in the ATSR instruments. The beam is chopped at 100Hz, a compromise between the optimum noise performance of the detector and a fast filter response in the signal processing chain. The main optical element is an ellipsoid mirror, by which the detector can view a 45° scan mirror through an anti-reflection coated ZnSe window.

All external radiance measurements are calibrated using two internal black bodies, operated at ambient temperature and at a programmable increment (typically 10 K) above ambient temperature. Each black body contains an embedded rhodium iron thermometer and is calibrated complete against a standard thermometer. External views can be programmed in fine increments at angles in a range spanning 180° from nadir to zenith.

9.3.1.2 Methodology

1. **Instrument development and testing:** SISTeR has been used on a number of validation campaigns already, collecting validation data points for the ATSR-2 instrument. Between deployments, the instrument undergoes extensive cleaning and maintenance, and calibration activities.

2. **Organisation of cruises/negotiation with ships-of-opportunity:** Negotiations with ships-of-opportunity take place, making use of both pre-existing contacts and new opportunities. Cruise availability and the participation of SISTeR are confirmed. Ancillary instruments that will be needed are identified, and acquired (by purchase, loan or hire).

3. **Instrument packing and shipping:** SISTeR is packed and arranged for shipping, with all required documentation, at times and places agreed with the cruise operator.

4. **Installation:** The SISTeR is generally mounted as far forward and as high as possible on the host ship, so that it is clear of "green water" and spray, and can view undisturbed water forward of the bow wave. Where possible, the viewing angle to the sea is kept within the range 15° - 40° from nadir. The instrument also requires a clear view to the sky at the complementary angle from zenith.

   The SISTeR is equipped with a quick release mount and is provided with a small turret, to which a mating bracket is attached. The turret should be mounted on a horizontal surface with a pattern of eight holes. A small horizontal platform, with the pattern pre-drilled, is also available and can be attached to handrails with U-bolts.

   The SISTeR requires 24V DC power and serial data connections. Instrument data are logged remotely on a laptop PC. Waterproof power supplies, serial modems and cable sets are available for runs of 100m or more with terminations for a variety of mains outlets.

5. **In situ data collection:** The SISTeR makes continuous measurements throughout the cruise, unless severe weather prevents data collection (in this instance, the instrument is covered to protect it). Typically, SISTeR radiances are sampled every 0.8s with the 10.8µm filter. Skin SSTs are calculated from the upwelling ocean radiance samples, corrected for a small, reflected sky radiance term with the complementary sky samples. Over a flat sea surface and for a narrow filter function, the upwelling radiance can be approximated closely as

$$R\_up = B(SST) + (1 - e)\, R\_down$$

where R_*up* and R_*down* are the upwelling sea and complimentary downwelling sky radiances, e is the emissivity of the sea surface and B(T) is the Planck function, each integrated over the instrumental filter function and field of view. R_*up* and R_*down* are measured directly by the SISTeR, and so the term B(SST) and hence the skin SST can be retrieved from these. The data are analysed on board and are available at the end of the cruise for comparison to satellite data. If urgently required, small amounts of data can usually be supplied whilst at sea. Supporting measurements of local meteorological parameters, bulk sea surface temperature and balloon-sonde profiles of atmospheric state will provide a valuable context for the skin SST data.

SISTeR Operation: All aspects of the SISTeR instrument, from the scan mirror position to the detector signal are accessible through variables defined in a C library. Control programs of arbitrary complexity can be written, but generally just a few lines of code are needed to define a scan sequence. When a control program is running, the complete instrument state is transmitted over a serial link to a laptop ground station after every measurement. All SISTeR measurement sequences contain repeated measurements of its two internal black bodies. In addition, to calculate the skin SST, the SISTeR is programmed to make measurements both of upwelling radiances from the sea surface and complementary downwelling sky radiances.

In the SISTeR longwave channels, the measured noise temperature for a 1 second sample at typical SSTs is less than 30mK. Measurements of an external CASOTS black body before, during and after a typical one-month validation campaign showed that the SISTeR calibration remained repeatable to better than 20mK, even though the scan mirror finish had deteriorated noticeably over the same period.

6. **Satellite data ordering and collection:** AATSR data will be ordered via the data co-ordinators.
7. **In Situ/satellite data matchups:** High resolution AATSR data contemporaneous with valid SISTeR data are required to perform a satisfactory validation study. Matchups between SST measurements collected in situ and cloud-free AATSR data will be made by Tim Nightingale at RAL.

9.3.1.3 Geographical Location

Operated on research vessels, the location of cruises depends on the availability of suitable cruises, berths and funding. In the initial validation phase, SISTeR participated in one cruise, the SCIPIO cruise operating in the West Indian Ocean in the geographical location:

Latitude 0-25° S
Longitude 50-70° E

9.3.1.4 Validation Activities

9.3.1.4.1 Up to Validation Workshop

A SISTeR was deployed on the RRS Charles Darwin as a part of the SCIPIO cruise with support from an EO enabling grant from the NERC for the beginning-of-life validation of the AATSR sea surface temperature sensor on the ESA ENVISAT satellite and the end-of-life validation of the ATSR-2 sensor on ERS-2. The cruise took place in the Indian Ocean, between the Seychelles and Mauritius, from the 1st June to the 11th July 2002. Figure 9.3.1.1-1 shows SISTeR installed on the foremast platform of the RRS Charles Darwin.

Figure 9.3.1.1-1 SISTeR mounted on the foremast platform of the RSS Charles Darwin

The cruise track is shown in Figure 9.3.1.4-2 with the availability of SISTeR data shown as a thickened line, and the positions of the seventeen ATSR-2 and AATSR overpasses indicated.

The SISTeR was operated for about half of the total cruise time, starting a couple of hours after leaving the Seychelles on the morning of the 1st June and finishing early on the morning of the 10th July, a day before making port in Mauritius. Skin sea surface temperatures varied between approximately 24°C and 28°C. Poor weather limited observations below approximately 10°S. Scattered cloud was generally present although there were sometimes clear skies, especially at night over the northern part of the cruise track.
In total, skin SST's were collected under a total of seventeen ENVISAT and ERS-2 overpasses. Of these, 4 are deemed suitable for validation points.

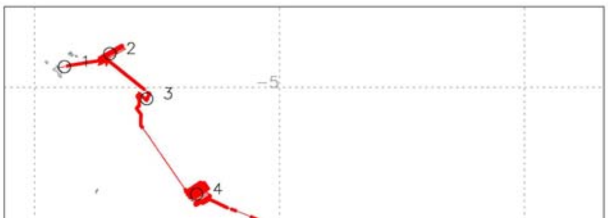

Figure 9.3.1.1-2 The track of the RSS Charles Darwin for the SCIPIO cruise, showing the availability of SISTeR data (thickened line) and the positions of the seventeen ATSR-2 and AATSR overpasses

9.3.1.4.2 Validation in Phase E

The validation team will continue to seek opportunities for using SISTeR for AATSR validation in Phase E. One possibility is participation in the CalCOFI cruise (TBD).

9.3.1.5 References

C.J. Donlon, T. Nightingale, L. Fielder, G. Fisher, D. Baldwin and I.S. Robinson 1999: The calibration and intercalibration of sea-going infrared radiometer systems using a low cost blackbody cavity, *J. Atmos. Oceanic Technol.*, **16**, 1183-1197.

C.J. Donlon and T.J. Nightingale, 2000: Effect of atmospheric radiance errors in radiometric sea-surface skin temperature measurements. *Applied Optics*, **39**, 2387-2392.

9.3.2 M-AERI, Minnett (590)

Global Validation of AATSR SST's is being carried out using precision measurements taken with the M-AERI, as described in A/O proposal 590. In addition to AATSR, the M-AERI has been used to validate AVHRR, MODIS, TRMM, ATSR-2 and AIRS. The work is funded by NASA and performed on a best efforts basis for AATSR.

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Dr Bill Emery, University of Colorado
Dr Simon Hook, NASA JPL
Dr Andy Jessup, University of Washington
Dr Frank Palluconi, JPL
Dr Goshka Szczodrak, RSMAS-MPO
Dr Gary Wick, NOAA

9.3.2.1 Instrumentation

The primary instrument being used to collect validation measurements is the M-AERI (Marine Atmosphere Emitted radiance Interferometer). The M-AERI is a robust, accurate, self-calibrating, sea-going Fourier-transform interferometric infrared spectroradiometer that is deployed on marine platforms to measure the emission spectra from the sea surface and marine atmosphere (Minnett *et al.* 2001). The environmental variables derived from the spectra include the surface skin temperature of the ocean, air temperature and surface emissivity. Use of the M-AERI for the validation of satellite-derived surface temperature fields, and the study of the physics of the skin layer has been extensive. The instrument has been deployed on numerous research cruises. In January 2000, it could be reported that on no occasion had data collection been terminated by an instrument failure (Minnett *et al.*, 2001). Other radiometers, operated by some of the Co-Investigators, will provide data in a similar fashion to the M-AERI. While not providing the spectral information available from the M-AERI, these instruments make measurements in spectral intervals defined by filters that correspond to the window channels of the AATSR. These radiometers are also well calibrated to provide accurate skin SST from ships.

The key instrument parameters of the M-AERI system are given in Table 9.3.2.1.

Scan Time	1 second in each direction
Spectral Coverage	5.5-18.2μm, 550-1800 cm^{-1} 3.3-5.5μm, 1800-3000 cm^{-1}
Spectral Sampling	0.48 cm^{-1}
Instrument field-of-view	45 mrad (full angle)
Dimensions	116 cm L x 71 cm W x 76 cm H
Mass (sensor)	93 Kg
Power (system)	1 kW maximum (approx.)

Table 9.3.2.1 Key instrument parameters of the M-AERI system

The M-AERI operates in the range of infrared wavelengths from 3 to 18 µm, measuring spectra with a resolution of 0.5 cm^{-1}. Two infrared detectors are used to achieve this spectral range, and these are cooled to 78K by a Stirling cycle mechanical cooler to reduce the noise equivalent temperature different to levels well below 0.1K. The M-AERI includes two internal black body cavities for accurate real-time calibration. A scan mirror directs the field of view from the interferometer to either of the black body targets to the environment from nadir to zenith. The mirror is programmed to step through a pre-selected range of angles, viewing either the atmosphere or the sea surface. The interferometer integrates measurements over a pre-selected time interval, usually a few tens of seconds, to obtain a satisfactory signal to noise ratio, and a typical cycle of measurements (two view angles to the atmosphere, one to the ocean, and calibration measurements) takes about 5 minutes. Pitch and roll sensors on the M-AERI mean the influence of the ship's motion on the measurements can be determined.

Instrument Operation: The M-AERI runs continuously under computer control, except for a brief period at midnight UTC when the computer reboots and undertakes some housekeeping tasks. This ensures that there is enough disk space for the new day's data. In the event of a shortage in disk space, the system will automatically delete the oldest day's data. It is thus important that an operator saves data to CD or tape on a regular basis to prevent data loss. Some data loss will occur in the event of heavy rain or sea spray. The mirror must remain clean and dry in order for the M-AERI to provide the required measurements. A rain sensor ensures that the mirror is moved into a 'safe' position in the event of light rain and spray. During heavy rain, the M-AERI is covered for protection.

Data Flow: In addition to interferometer data, a comprehensive set of housekeeping data are collected from the blackbody subsystem, the mirror controller, the environmental monitors (temperature, humidity, pressure and precipitation), a global positioning system to give location and an inclinometer. The housekeeping data are sampled (200 average sample) and recorded at 5-second intervals. These are useful for quality control and data analysis.

9.3.2.2 Methodology

In the following discussion, the operational methodology given here for the M-AERI, will be applied, where appropriate, to the radiometer deployments organized by the Co-Investigators.

1. **Instrument development and testing**: the M-AERI has now been used on a number of data collection exercises, and is considered proven in its ability to measure SST to an accuracy of <0.1K. Periodically the M-AERI is brought together with similar instruments, such as those of the Co-Investigators and the SISTeR (UK) and the DAR011 (Australia), for cross-comparisons and calibration checks against reference black body targets.

   i. **Intercalibration at Miami, 1998**: One such inter-comparison took place in the form of a workshop, held at RSMAS in March 1998. The purpose of the workshop was to provide a framework in which investigators using infrared radiometers, spectrometers and imaging devices could come together to compare instruments, calibration targets and measurement protocols. This would ensure consistent and accurate datasets for future use in validating infrared retrievals of surface temperature over land and sea.

An instrument platform to support remote sensing and meteorological instruments was constructed on the roof of the Marine Science Centre at RSMAS. A 15m high meteorological tower next to the instrument platform provided data on wind speed and direction, air temperature and humidity, downwelling long and short wave radiation. Floats in the water in front of the building provided a near surface in situ surface temperature. Instruments were compared to each other and to internationally recognised black body calibration targets.

Results of the 1998 inter-comparison workshop can be found at http://www.rsmas.miami.edu/ir and has been reported by Kannenberg and Palluconi, 1998 (Kannenberg, R., and F. Palluconi, Joint Rosenstiel School of Marine and Atmospheric Science (RSMAS) Committee on Earth Observation Satellites (CEOS) Validation Workshop, The Earth Observer, 10 (3), 38-42, 1998; http://eospso.gsfc.nasa.gov/eos_observ/5_6_98/may_jun98.html). Comparing M-AERI to a blackbody maintained by the National Institute of Standards and Technology, for example, an error analysis indicated that the absolute accuracy of M-AERI sea surface skin temperatures does indeed meet or exceed the design goal of 0.1C absolute accuracy (Minnett *et al*., 2001).

ii. **Intercalibration at Miami, 2001.** A second international infrared radiometry workshop and inter-comparison took place at the Rosenstiel School of Marine and Atmospheric Science, University of Miami, from May 28 to June 1, 2001. The workshop was coordinated by Dr Peter Minnett of RSMAS and Dr Ian Barton of CSIRO, and aimed to compare radiometers using measurements of SST taken on a short cruise of the R/V Walton Smith, and calibrate radiometers against a NIST-certified blackbody calibration target.

Six different makes of radiometers were calibrated against the NIST standard Black Body in the laboratory and seven radiometers were mounted on the RV Walton Smith (a research ship owned by the University of Miami) for an intercomparison under sea-going conditions. Radiometers tested both in the laboratory and on the Walton-Smith included the ISAR5C, DAR011, SISTeR and the M-AERI (ship only). Figure 9.3.2.2-1 shows the radiometers mounted on the ship; the cruise track is shown in Figure 9.3.2.2-2, and Figure 9.3.2.2-3 shows a time series of the measurements made. Table 9.3.2.2-1 is a summary showing the results of comparing pairs of radiometers; it shows small differences and confirms the suitability of all radiometers for SST validation.

Figure 9.3.2.2-1 View from above of the radiometers mounted on the R/V Walton-Smith. From fore to aft, they are the SISTeR, ISAR5C (hidden), CIRMS, M-AERI and DAR011

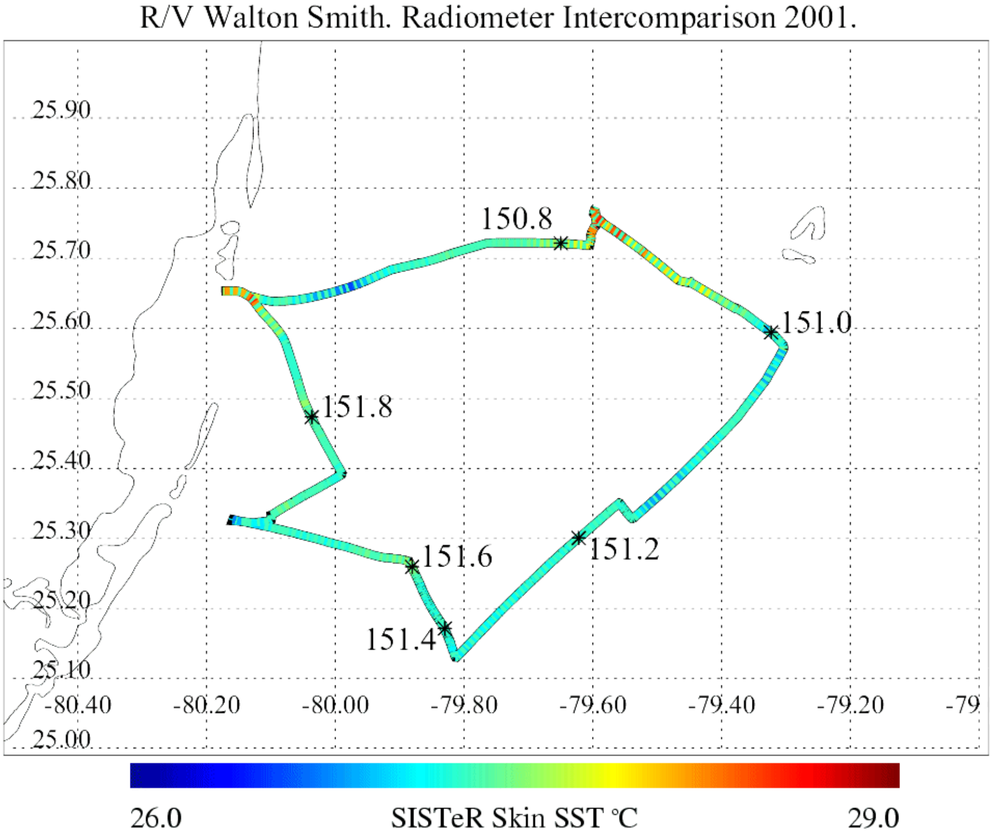

Figure 9.3.2.2-2 Cruise track of the R/V Walton Smith for the radiometer intercomparison, 2001

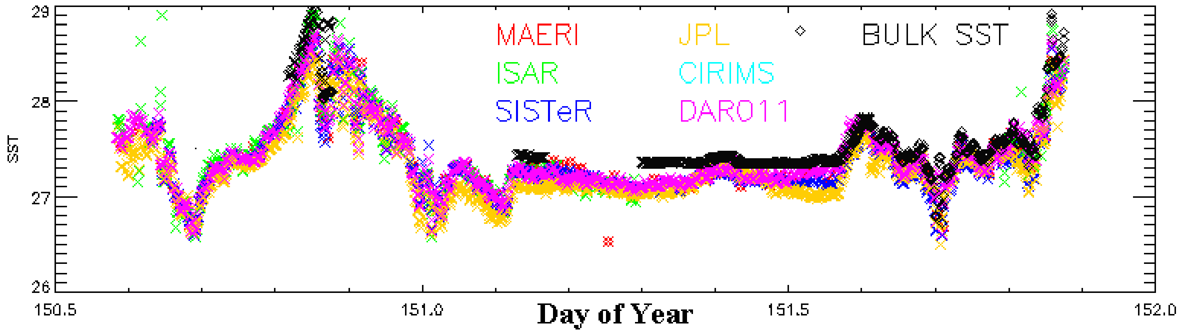

Figure 9.3.2.2-3 Time series of the measurements made on the R/V Walton Smith

Means and standard deviations of the estimated skin SST differences between pairs of radiometers for the entire cruise period, and for each half of the cruise.

Time	150.50 to 152.00			150.50 to 151.25			151.25 to 152.00		
Radiometer Pair	Mean (K)	Std.Dev (K)	N	Mean (K)	Std.Dev (K)	N	Mean (K)	Std.Dev (K)	N
MAE-ISA	0.002	0.135	80	0.005	0.135	69	–0.015	0.135	11
MAE-SIS	0.046	0.066	144	0.046	0.066	74	0.045	0.068	70
MAE-JPL	0.007	0.114	148	0.052	0.111	77	-0.042	0.096	71
MAE-DAR	-0.008	0.076	149	0.022	0.071	78	-0.041	0.067	71
ISA-SIS	0.038	0.101	79	0.030	0.101	67	0.085	0.093	12
ISA-JPL	0.026	0.142	81	0.027	0.141	70	0.018	0.150	11
ISA-DAR	0.007	0.114	80	0.019	0.112	69	-0.064	0.107	11
SIS-JPL	-0.048	0.099	144	-0.009	0.103	74	-0.088	0.078	70
SIS-DAR	-0.053	0.074	144	-0.019	0.054	74	-0.088	0.076	70
JPL-DAR	-0.014	0.103	148	-0.028	0.102	77	0.000	0.102	71

Table 9.3.2.2-1 Results from the Miami Intercomparison (Barton *et al* in press)

A full report of the workshop can be found in the following reports and papers.

Minnett, P. and Barton, I., 2001, ‘The second international infrared radiometer calibration and inter-comparison’. Report to ESA.

Rice, J. P., J. J. Butler, B. C. Johnson, P. J. Minnett, K. A. Maillet, T. J. Nightingale, S. J. Hook, A. Abtahi, C. J. Donlon and I. J. Barton. The Miami2001 Infrared Radiometer Calibration and Intercomparison: 1. Laboratory Characterization of Blackbody Targets, *Journal of Atmospheric and Oceanic Technology*.

Barton, I. J., P. J. Minnett, C. J. Donlon, S. J. Hook, A. T. Jessup, K. A. Maillet and T. J. Nightingale. The Miami2001 infrared radiometer calibration and inter-comparison: 2. Ship comparisons, *Journal of Atmospheric and Oceanic Technology*.

2. **Organisation of Cruises/ Negotiation with ferries/ships-of-opportunity.** RSMAS has 3 M-AERI instruments that are used for AATSR validation (given the availability of funding). Specific details of campaigns are mentioned in Section 9.3.2.4. Recent

negotiations have led to the installation of a M-AERI on the Royal Caribbean cruise ship, the 'Explorer of the Seas', in October 2000. Continuing negotiation and international liaison has enabled participation in cruises worldwide in the past, and given appropriate funding, this will continue throughout Phase E.

3. **Installation.** Once negotiations are completed, the M-AERI is installed on the vessel. The location on the ship must provide a clear view of the sea surface ahead of the ship, beyond the bow wave, and a clear view of the sky. This generally results in a fairly exposed position, which leads to data loss during storms or heavy rain when the instrument is put into a 'safe mode' or is covered by a tarpaulin.

4. **In Situ Data Collection.** As the vessel continues normal operating duties, the M-AERI makes measurements as described above. On shorter cruises such as the weekly cruise of the Explorer of the Seas, the instrument can be left to run almost autonomously, with little technical assistance needed. Data are downloaded on a weekly basis as the boat comes into port in Miami. On longer cruises, a dedicated technician/scientist accompanies the instrument on the cruise, maintaining it and ensuring data are collected.

   Interferometer and housekeeping data are collected together. The merged data stream is recorded in a customized data format (DMW, developed at the University of Wisconsin). After creation of the DMW format data files, a sequence of FORTRAN language modules are executed. 5 processing steps are performed on the raw data.

   - A correction for detector nonlinearity is applied to the longwave band.
   - The forward and backward Michelson scans for each of the longwave and shortwave bands are calibrated individually.
   - The forward and backward scans are averaged for each band.
   - A finite field of view correction is applied to each calibrated spectrum.
   - The spectra are resampled to a standard wave-number scale common to all M-AERI systems.

5. **Satellite data ordering and collection:** AATSR will be ordered in advance, depending on the geographic and temporal location of M-AERI and filter radiometers.

6. **In situ/satellite data matchups:** High resolution (1km) AATSR data contemporaneous with valid M-AERI and radiometer data are required to perform a satisfactory validation study. Matchups between SST measurements collected by M-AERI and cloud free AATSR imagery will be made at RSMAS. Similar measurements made by the Co-Investigators will be collated at RSMAS. These data will be e-mailed to the VS, who will be responsible for their analysis and for feeding them into the 'validation loop'. Validation reports will be sent to the VS on a monthly basis.

   Given limitations of available personnel at RSMAS to perform the in situ/satellite measurements, this work will be performed with help, where possible, from personnel at Leicester University.

9.3.2.3 Geographical Location

Ideally, M-AERI and other instruments will validate SST measurements from AATSR on a global scale. Particular attention will be paid to capturing the full range of atmospheric variability from the polar to equatorial zones. For the ocean, emphasis will be placed on deployments on long trans-oceanic quasi-meridional sections in the Pacific and Atlantic Oceans, and targeted campaigns in regions of known 'difficult' conditions, such as the outflow of continental aerosols.

9.3.2.4 Validation Activities

9.3.2.4.1 Up to Validation Workshop

Three MAERI instruments were deployed in the initial validation phase, up to the validation workshop.

- **Royal Caribbean Cruise Line Ship**

One of the M-AERI instruments was deployed continuously on board the Royal Caribbean 'Explorer of the Seas' Cruise ship. This ship makes a 7-day cruise round the Caribbean, docking in Miami every Saturday. A weekly changeover of passengers allows scientists to download data and maintain the instrument. For more details see http://www.rsmas.miami.edu/rccl/.

Two cruise tracks were followed in alternate weeks, an Eastern Caribbean Circuit (Figure 9.3.2.4.1-1) and a Western Caribbean Circuit (Figure 9.3.2.4.1-2). These are shown in Figures 9.3.2.4-1 and 9.3.2.4-2. For the Eastern Circuit, the Liner sails a weekly seven-night eastern Caribbean itinerary from Miami, down to Haiti, Puerto Rico, US Virgin Islands, Nassau in the Bahamas and back across the Gulf Stream.

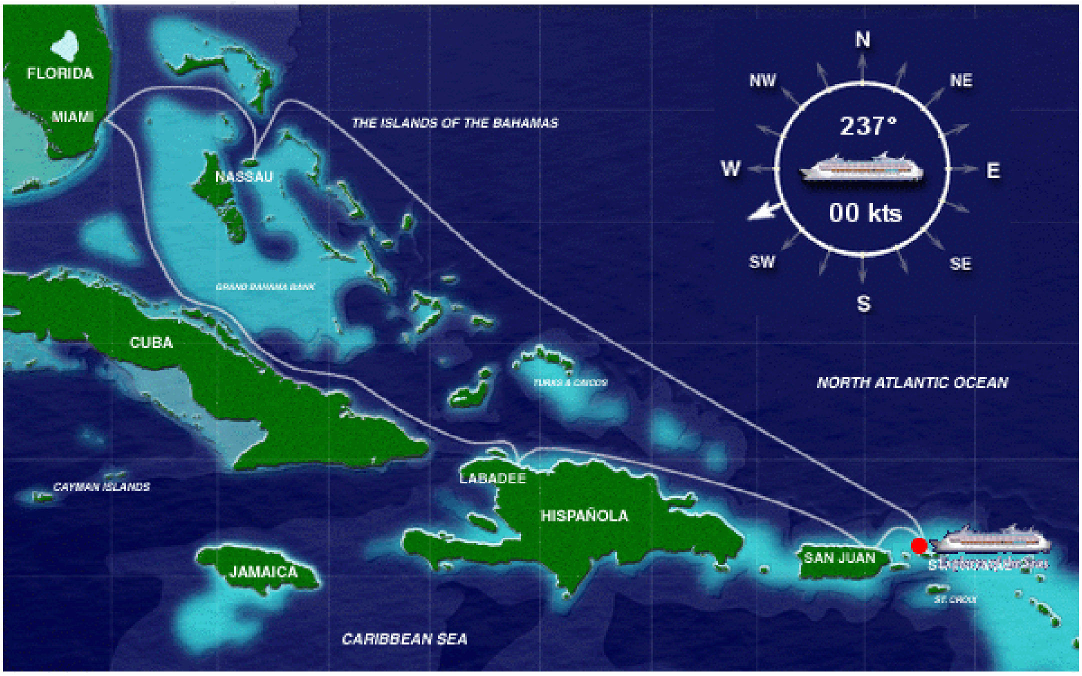

Figure 9.3.2.4.1-1 Eastern Caribbean Circuit of the Royal Caribbean 'Explorer of the Seas' Liner, carrying a M-AERI making measurements of SST
(Source of image: http://www.rsmas.miami.edu/rccl/obs/ex-rt-obs.pl)

Figure 9.3.2.4.1-2: Western Caribbean Circuit of the Royal Caribbean 'Explorer of the Seas' Liner, carrying a M-AERI making measurements of SST

Matchups with AATSR data are being carried out at the University of Leicester, in collaboration with Peter Minnett. Although the ship is at sea every night and two days a week, 52 weeks a year, the expected numbers of matchups with AATSR data are only 15-25. To date, over 180 files have been uploaded to the NILU database.

- **Research Vessels/Ships of opportunity**

The other two M-AERI instruments were deployed on 3 cruises in the initial validation phase.

1. Arctic, 18th September 2002 to 24th October 2002

MAERI-03 was deployed on the Canadian Icebreaker Pierre Raddison in the Arctic (vicinity 70.5N, 131W) from 18th September to 24th October 2002. MAERI data were taken on 26 days during the cruise although it was cloudy and overcast for many of these. The cruise track is shown in Figure 9.3.2.4.1-3.

2. Mediterranean, 21st September to 9th October 2002

MAERI-02 was deployed on the Urania in the Mediterranean, from 21st September to 9th October 2002. The cruise track is shown in Figure 9.3.2.4.1-4.

3. Seattle to Sydney, 4th November to 2nd December 2002

MAERI-02 was deployed on the Polar Sea, for a cruise from Seattle to Sydney. Unfortunately soon after leaving Seattle, the ship went through a bad storm in the NE Pacific and MAERI-02 was damaged. It was returned to Miami for repair.

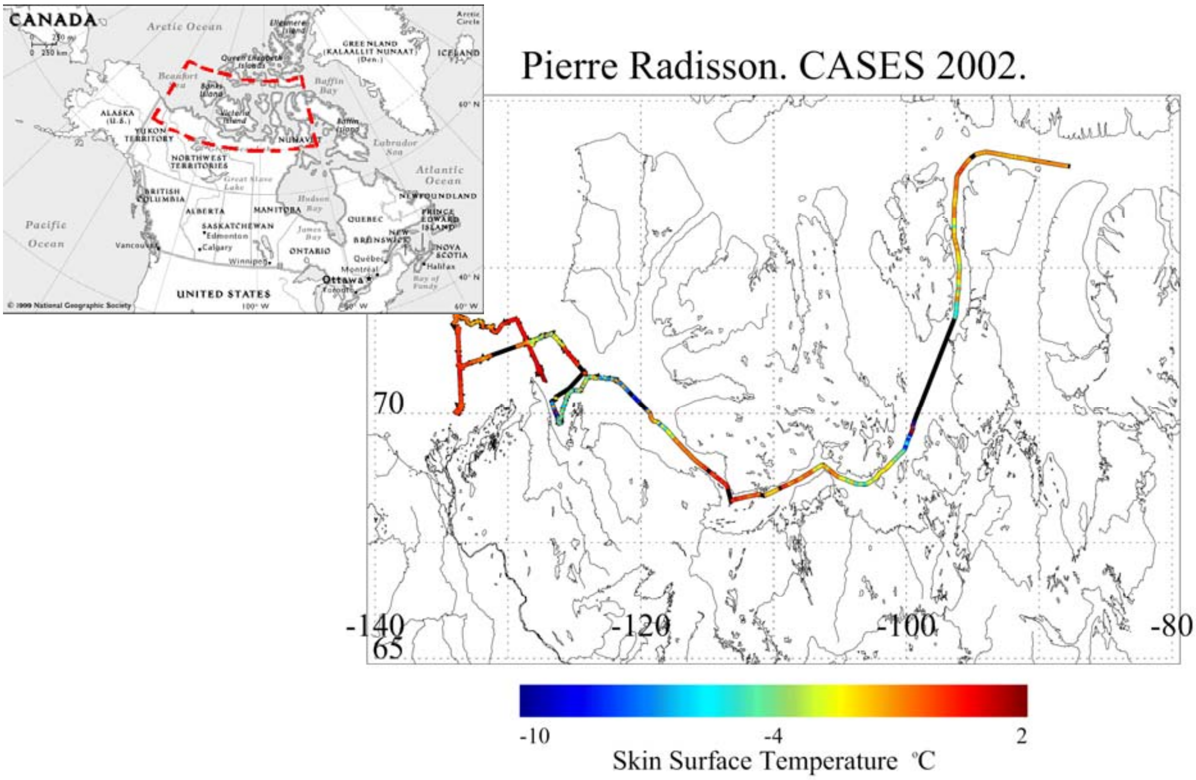

Figure 9.3.2.4.1-3 Cruise track of the Canadian Icebreaker Pierre Radisson, deploying the MAERI-03 for AATSR validation

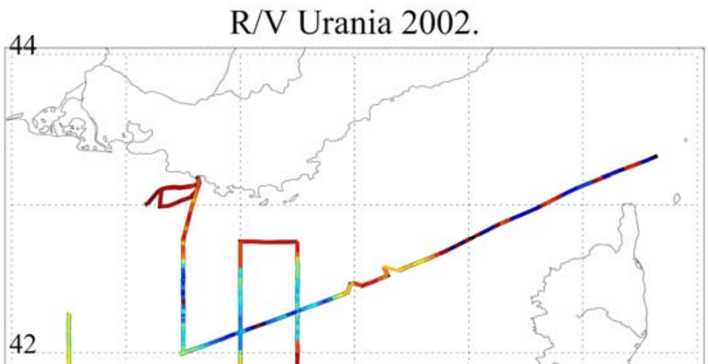

Figure 9.3.2.4.1-4 Cruise track of the Urania, deploying the MAERI-02 for AATSR validation

MAERI cruises since 1996 are shown schematically in Figure 9.3.2.4.1-5.

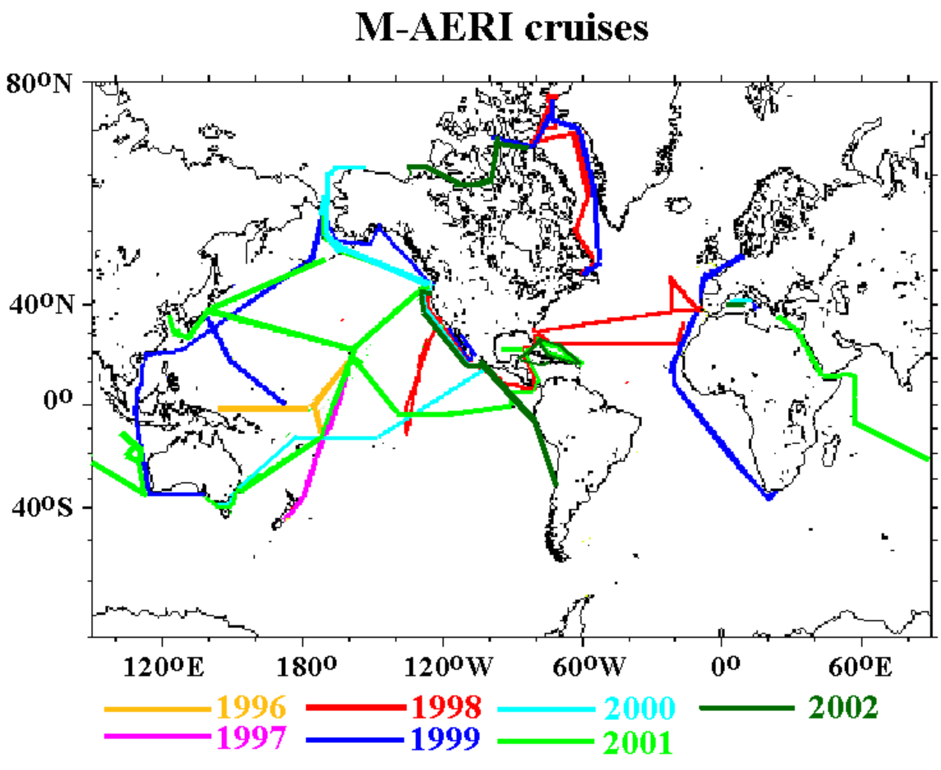

Figure 9.3.2.4.1-5 Schematic representation of the past cruises for the University of Miami's M-AERI systems

9.3.2.4.2 Validation in Phase E

Given the availability of funding, AATSR validation using the MAERI will continue throughout Phase E. Validation activities currently planned for 2003 are shown in Table 9.3.2.4.2-1.

Ship	Cruise Location	Dates
Explorer-of-the-Seas	Caribbean	Continuous, with 2 weeks dry dock in January 2003
Polar Sea	Melbourne-Yokoyama-Sydney	March-April 2003
Urania	Mediterranean	March-May 2003
Franklin	Canadian Arctic	September 2003 (for 12 months TBC)
Tangaroa	Southern Ocean	November 2003 (TBC)
Polar Star	Seattle - Sydney	November - December 2003 (TBC)

Table 9.3.2.4.2-1 MAERI validation cruises currently planned for Phase E

CIRIMS measurements

The CIRIMS (the Calibrated InfraRed In situ Measurement System) is an autonomous system for measuring the ocean skin temperature from ships, developed at the Applied Physics Laboratory at the University of Washington by Dr. Andrew Jessup. Commercially available infrared pyrometers and a precision blackbody are used, housed in a temperature-controlled enclosure. A total of three units have been fabricated and deployed at sea for over 700 days since 1998.

During the GasEx 2001 cruise, T_{skin} measured by CIRIMS (combined data with and without the window) was compared to T_{skin} measured by the M-AERI for all available overlapping data (15 days, or 357 hours, over a 35-day period). The RMS difference was 0.13 °C, with zero mean. For clear skies using only the CIRIMS data with the window, the RMS difference was 0.12 °C and the mean±std dev was –0.02±0.11 °C. The degree to which the measurements agree is illustrated in the time series plot in Figure 1, which shows the M-AERI data plotted with the CIRIMS data with and without the window. This comparison demonstrates that the scatter in the CIRIMS data is comparable to that of the M-AERI. Using the M-AERI as the standard for judging the accuracy of the CIRIMS, the comparison to date demonstrates that the CIRIMS meets the design goal of ± 0.1 °C.

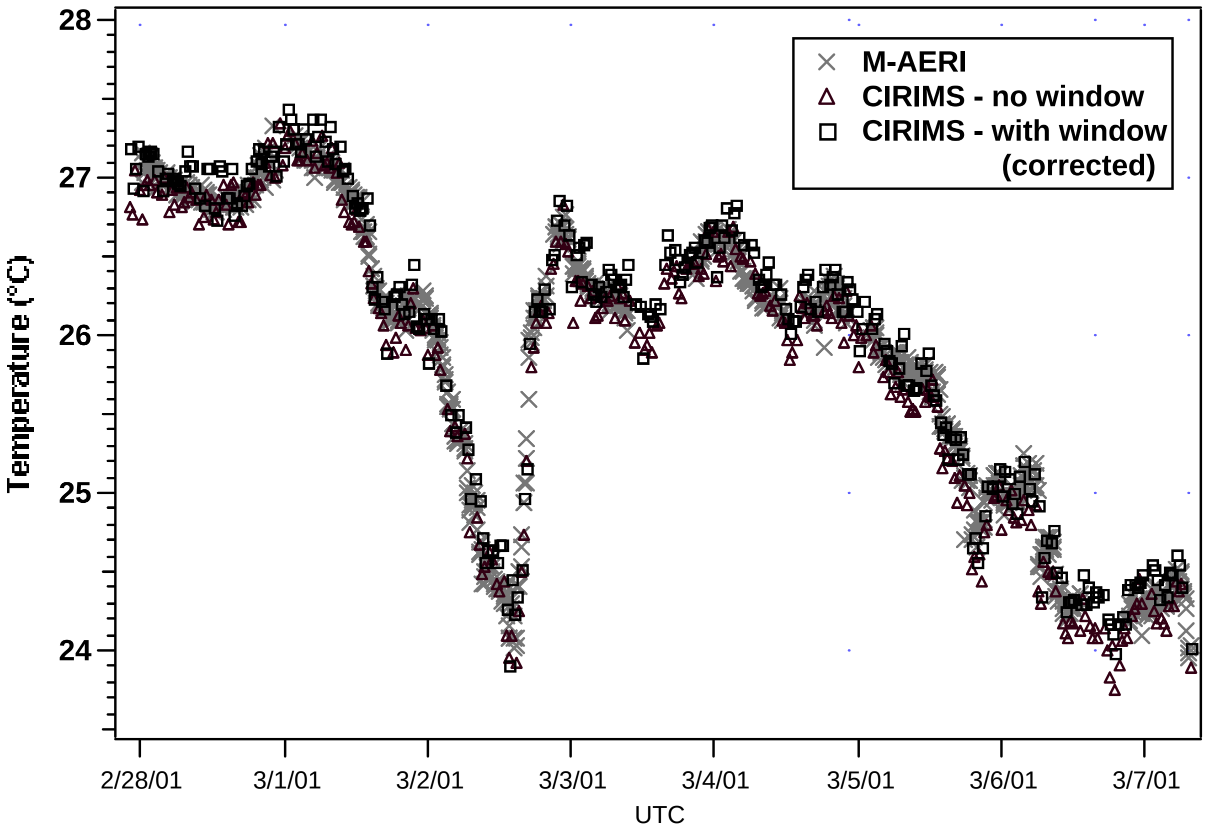

Figure 1. Time series of skin SST measured by M-AERI and CIRIMS over an 8-day period on the GasEx 2001 cruise. The agreement at times is excellent

Two units will be deployed continuously for 3 years beginning in 2003. The data will be telemetered daily via Iridium modem and made available as quickly as possible following quality control. The first unit will be deployed on the NOAA R/V Ronald H. Brown beginning in April 2003. Candidate ships for the second CIRIMS are the NOAA R/V Ka'imimoana or the University of Washington R/V Thompson. These measurements will be made available through Phase E.

Reference

Jessup, A. T., R. Fogelberg, and P. J. Minnett, Autonomous shipboard infrared radiometer system for *in situ* validation of satellite SST, Earth Observing Systems VII, Proc. SPIE Vol. 4814, 222-229, 2002.

9.3.2.5 Data Requirements

Throughout Phase E, the project team will continue to require L2 and L1b AATSR data over the area of interest. They expect to continue receiving CD's from the UK-PAC containing all AATSR L2 data. Specific scenes of L1b data will be ordered as and when necessary.

During Phase E, data should be sent to Dr Peter Minnett at RSMAS (address as above).

9.3.3 DAR011, Barton (9202)

Validation activities from Hobart are being conducted by Dr Ian Barton, CSIRO. A precision radiometer, the DAR011, is being operated on board research ships-of-opportunity, such as the RV Franklin and the RV Southern Surveyor.

Principal Investigator: Dr Ian Barton
CSIRO Marine Research
Castray Esplanade
Hobart, Tasmania 7000
Ian.Barton@csiro.au

9.3.3.1 Instrumentation

The DAR011 radiometer is a single-channel, self-calibrating, infrared radiometer developed and built within CSIRO. The radiometer has a heritage going back many years and is the culmination of developments leading to a reliable accurate instrument. A rotating 45 degree plane mirror sequentially views the sea, a hot black body calibration target, the sky, and finally an ambient temperature black body calibration target. The incoming radiation is physically chopped against a second ambient temperature black body and the chopped radiation is focused with a 45 degree parabolic front surfaced mirror onto a pyroelectric detector. Before reaching the detector the radiation passes through an interference filter that passes radiation with wavelengths between 10.5 and 11.5 µm. The temperatures of the two calibration black bodies are accurately monitored providing good absolute radiometric accuracy.

During 2001 the DAR011 radiometer was included in the Miami2001 infrared radiometer calibration and inter-comparison. The radiometer was calibrated against a NIST-designed black body target, and compared against other similar radiometers used for the validation of satellite-derived surface temperatures, and found to perform with a high degree of accuracy.

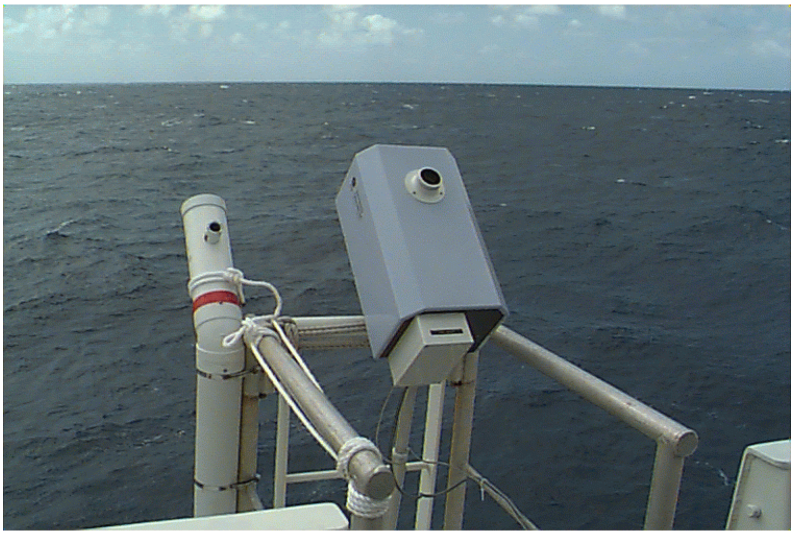

Figure 9.3.3.1-1: The DAR011 radiometer, mounted on the RV Franklin, used for validation activities based in Hobart (Photograph from CSIRO)

9.3.3.2 Methodology

1. **Instrument development and testing**: the DAR011 has now been used on a number of data collection exercises. It was involved in the intercalibration exercise in Miami in 1998 and 2001.

2. **Organisation of Cruises/ Negotiation with ferries/ships-of-opportunity.** The Research Vessel, the Franklin, operates in Australian waters. It has a full complement of oceanographic and meteorological instrumentation that provides the supporting marine and atmospheric data needed for analysis. The frequency of cruises is determined by berth availability, ship schedule and funds to cover travel, ship time and at-sea allowances.

3. **Installation.** Once negotiations are completed, the DAR011 is installed on the vessel.

4. **In Situ Data Collection.** The DAR011 makes continuous measurements throughout the cruise. Radiosondes are launched as satellite overpass times when the sky is free of clouds. The radiometer views the sky on a regular basis to ensure that an accurate correction can be applied to account for the non-unity emissivity of the sea surface. The data are analysed on board and are available at the end of the cruise for comparison to satellite data. If required urgently, small amounts of data can be usually supplied via the internet whilst at sea.

5. **Satellite data ordering and collection:** AATSR will be ordered from the ESA User Services Facility in advance, depending on the geographic and temporal location of DAR011 instrument.

6. **In situ/satellite data matchups:** High resolution (1km) AATSR data contemporaneous with valid DAR011 data are required to perform a satisfactory validation study. Matchups between SST measurements collected in situ and cloud free AATSR imagery will be made at CSIRO, Hobart. These data will be e-mailed to the validation scientist, and will enter the 'validation loop'. After the AATSR SODAP and during the commissioning phase (2-6 months after launch), validation reports will be sent to the VS on a monthly basis.

9.3.3.3 Geographical Location

Cruises usually occur in Australian waters - but on occasion, data will be collected from areas some distance from Australia. Cruises will be targeted that promise a high probability of clear skies, typically cruises in tropical waters during the months of June to October, when the monsoon activity is north of the equator and clear skies are frequent.

9.3.3.4 Validation Activities

9.3.3.4.1 Up to Validation Workshop

In the time period up to the Validation Workshop, the DAR011 was been deployed on four cruises of the AIMS RV Lady Basten. The dates of the cruises and the number of validation points obtained on each one is shown in Table 9.3.3.4.1-1.

Dates of RV Lady Basten Validation Cruises	No. of Validation Points Collected
24th May - 2nd June 2002	2
5- 14th June 2002	4
19 - 28th September 2002	3
21 - 30th October 2002	4

Table 9.3.3.4.1-1 Number of validation points collected by the DAR011 in the initial validation phase

Each cruise was for a period of nine days and between 2 and 5 validation coincidences were obtained on each cruise. The first two cruises were held late in May and June and were right at the start of the AATSR commissioning period. Unfortunately there were some days when good ship-based data were collected, but the instruments in ENVISAT were not operating. The data collected during the first two cruises were also used to validate the ATSR-2 derived SST.

To date, two of the validation points have been used to validate AATSR data. In situ/satellite matchups show excellent agreement (within 0.2°C).

9.3.3.4.2 Validation in Phase E

Validation using the DAR011 will continue in Phase E. Table 9.3.3.4.2-1 shows the validation cruises currently planned. In addition there may well be a number of as-yet-unplanned piggy-back cruises.

Location of validation cruise planned for Phase E	Date of Cruise
Gulf of Carpentaria	9 May-10 June 2003
Out of Darwin (Timor Gap)	11-21 June 2003
Other cruises as selected	TBD

Table 9.3.3.4.2-1 Validation cruises planned for the DAR011 in Phase E

9.3.3.5 Data Requirements

Throughout Phase E, the project team will continue to require L2 and L1b AATSR data over the area of interest. They expect to continue receiving CD's from the UK-PAC containing all AATSR L2 data. Specific scenes of L1b data will be ordered as and when necessary.

During Phase E, data should be sent to Dr Ian Barton at CSIRO Marine Research (address as above).

10 Validation of the Level 1b GBTR product, AATSR visible/near infrared data

The level 1b thermal channels (3.7µm, 11µm and 12µm) will be validated inherently through the validation of the level 2 SST product (Section 9) and the land surface temperature product (Section 11). Validation of the visible/near infrared channels (0.55µm, 0.67µm, 0.87µm and 1.6µm) will be carried out over land and cloud. This is done in two ways, through vicarious validation and through the collection of ground measurements taken during field campaigns.

Figure 10-1 gives the names of PI's leading different project involved in the validation of visible/near infrared channels, together with their project ID number. The work by Smith and Prata is considered core validation. The work of Stammes, Hagolle and Watts is being carried out primarily for the validation of other instruments (for SCIAMACHY and MERIS). It is not considered core AATSR validation activities, although data from these activities will be useful for initial AATSR validation and their work is included here.

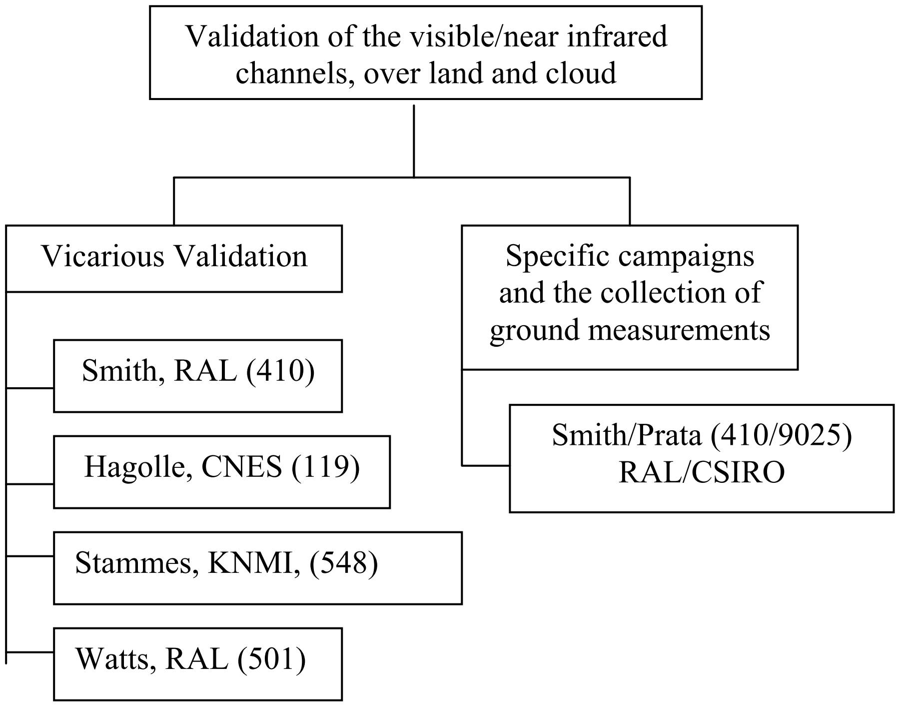

Figure 10-1: PI's involved in validation of the AATSR visible/near infrared channels

10.1 Vicarious Validation

Vicarious validation compares top-of-atmosphere (TOA) radiances from AATSR to TOA measurements from similar sensors. At the present time, there are four projects that will do vicarious validation for AATSR, over stable land sites and over cloud.

10.1.1 Vicarious Inter-Calibration of AATSR and MERIS using terrestrial targets, Smith (410)

Principal Investigator: Dr David Smith
Rutherford Appleton Laboratory
CCLRC, Chilton
Didcot, Oxfordshire
OX11 0QX

Co-Investigators: Dr Chris Mutlow, RAL
Dr Carina van Eijk, Institute of Applied Physics
Dr Fred Prata, CSIRO Atmospheric Research

10.1.1.1 Methodology

Smith is comparing AATSR- and MERIS top-of-atmosphere radiances for a range of desert regions and Greenland ice, and monitoring the long-term stability of the instruments. This will lead to a robust characterisation of the in-orbit performance of the instruments and the on-board calibrators. Using similar channels on AATSR and MERIS enables direct comparisons of the instrument calibrations to be made, Figure 10.1.1.1-1. The measurements will be particularly useful to check for any across track variations in the calibration of MERIS. The results will also be compared against the existing ATSR-2 data for the same scenes. In-situ measurements provided by CSIRO over Australian sites will validate the top-of-atmosphere measurements (see Section 10.2.1).

Outputs from the work include:
- Time series of uncorrected top-of-atmosphere reflectances.
- Calibration drift corrections.
- Reflectances corrected for atmospheric absorption (not aerosols).
- Intercomparisons with MERIS and ATSR-2 reflectances.

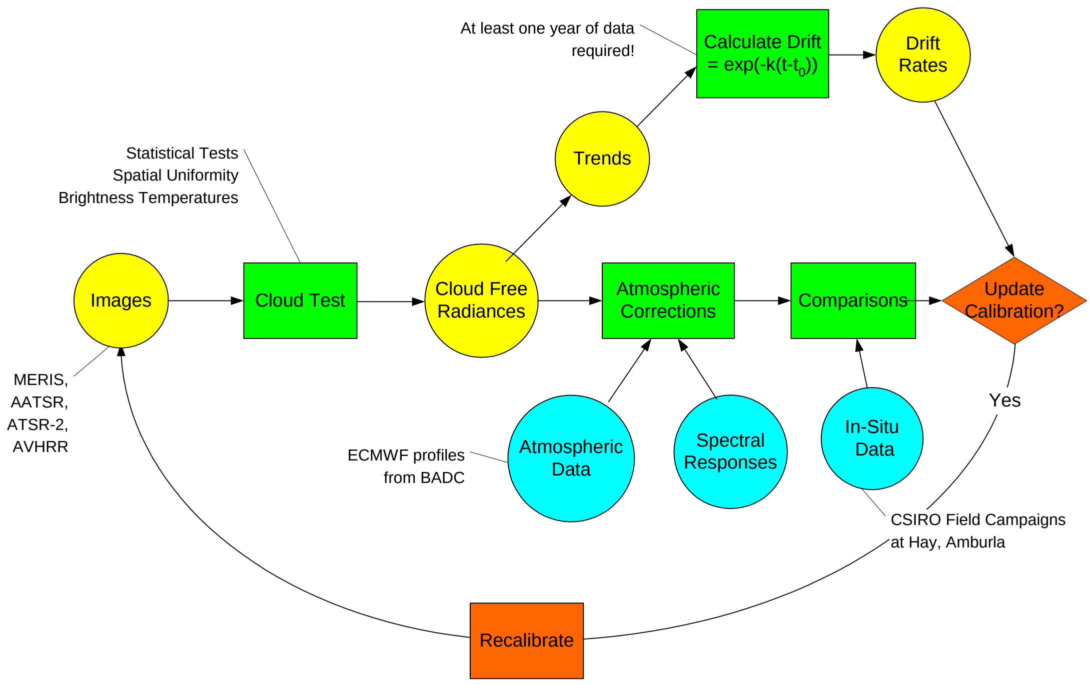

Figure 10.1.1.1-1: Intercomparison scheme for AATSR, ATSR-2 and MERIS.

10.1.1.2 Geographic Locations

Table 10.1.1.2-1 gives the latitudes and longitudes of the main regions being studied. These include the CNES sites listed in Table 10.1.2.3-1. Other sites may also be required as the investigation progresses.

10.1.1.3 Validation Activities

10.1.1.3.1 Up to Validation Workshop

The delay in data distribution meant that Smith was only able to do some preliminary comparisons between AATSR, ATSR-2 and MERIS in the period up to the validation workshop. The majority of the work outlined for the 'initial' validation phase will therefore be done in Phase E.

10.1.1.3.2 In Phase E

Given the appropriate funding, Smith will continue to monitor stable sites over the duration of the mission to determine any long-term instrument drift.

Site Name	Lat centre (°)	Long centre (°)	Lat_min	Lat_max	Long_min	Long_max
Arabia1	18.88	46.76	18.38	19.38	46.26	47.26
Arabia2	20.13	50.96	19.63	20.63	50.46	51.46
Arabia3	28.92	43.73	28.42	29.42	43.23	44.23
Sudan1	21.74	28.22	21.24	22.24	27.72	28.72
Niger1	19.67	9.81	19.17	20.17	9.31	10.31
Niger2	21.37	10.59	20.87	21.87	10.09	11.09
Niger3	21.57	7.96	21.07	22.07	7.46	8.46
Egypt1	27.12	26.1	26.62	27.62	25.6	26.6
Libya1	24.42	13.35	23.92	24.92	12.85	13.85
Libya2	25.05	20.48	24.55	25.55	19.98	20.98
Libya3	23.15	23.1	22.65	23.65	22.6	23.6
Libya4	28.55	23.39	28.05	29.05	22.89	23.89
Algeria1	23.8	-0.4	23.3	24.3	-0.9	0.1
Algeria2	26.09	-1.38	25.59	26.59	-1.88	-0.88
Algeria3	30.32	7.66	29.82	30.82	7.16	8.16
Algeria4	30.04	5.59	29.54	30.54	5.09	6.09
Algeria5	31.02	2.23	30.52	31.52	1.73	2.73
Mali1	19.12	-4.85	18.62	19.62	-5.35	-4.35
Mauritania1	19.4	-9.3	18.9	19.9	-9.8	-8.8
Mauritania2	20.85	-8.78	20.35	21.35	-9.28	-8.28
Libyan Desert	22	28.5	21	23	28	29
Dunhuang	40.095	94.155	40.02	40.17	94.01	94.3
Sonora	31.8	-113.86	31.54	32.06	-114.18	-113.54
Hay	-34.382	145.292	-34.632	-34.132	145.042	145.542
Amburla	-23.285	133.119	-23.535	-23.035	132.869	133.369
Thangoo	-18.1	122.26	-18.35	-17.85	122.01	122.51
Greenland	73.75	-40	(point and radius of 488 km)			

Table 10.1.1.2-1 Geographic Location of the sites used for Vicarious Validation

10.1.1.4 Data Requirements

The following data are required:

- AATSR level 1b (GBTR) images for selected calibration sites over the whole mission
  - All channels (3.7µm, 11µm, 12µm, 1600nm, 870nm, 660nm, 555nm)
- MERIS level 1b radiances for selected calibration sites over the whole mission
  - 520, 560, 620, 665, 681, 865, 890 nm channels
  - Desert reflectances obtained using the METRIC tool
- ATSR-2 GBT images containing all channels (Smith already has a complete time series for selected sites).
- ECMWF atmospheric profiles from BADC
- In situ measurements from CSIRO (see Section 10.2.1)

10.1.2 Validation of MERIS calibration using natural targets, Hagolle (119)

A limited amount of vicarious calibration of the AATSR visible channels will be undertaken as part of the MERIS calibration activities. The primary aim of this activity is to validate and monitor the absolute calibration of MERIS using a variety of natural targets, including stable desert sites. However, over desert sites, it is also possible to conduct vicarious calibration of the AATSR visible channels and perform cross calibration between MERIS, AATSR and other sensors.

Details of the MERIS calibration exercise using natural targets are contained in AD8 (the MERIS Cal/Val Implementation Plan). The AATSR aspects of this work are described here. It is important to note that this work is not central to CNES' activities and is only designed to compliment the MERIS calibration. Therefore it is a lower priority task for CNES and will be performed on a best efforts basis.

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10.1.2.1 Instrumentation

This method uses the characterisation of the properties of 20 desert sites that was obtained with POLDER 1 instrument. Given the very good stability with time of these sites, no in-situ measurement is needed for this method. Measurement protocols are not applicable for this work.

10.1.2.2 Methodology

Twenty desert sites in North Africa and Arabia have been selected for their spatial uniformity and temporal stability, using Meteosat data. The sites are quite lambertian and the directional variations of their reflectance has been monitored using POLDER data. Since POLDER data makes a very complete sampling of the directional conditions, it is nearly always possible to find a POLDER acquisition with solar and viewing angles very close to the angles of any sensor measurement. POLDER can thus be used as a transfer radiometer to make cross calibrations between sensors, even if they do not have the same scanning geometry.

The main error sources are the aerosols and the variation of the site reflectance: aerosols can modify the top of atmosphere reflectance of the desert sites, but it is expected that after averaging a lot of measurements, the aerosol effect will mainly affect the results as a noise and not as a bias. The cross-calibration results could also be affected by long term variations of the desert sites reflectance, but averaging the results for 20 desert sites reduces the eventual variations. Since 1996, CNES has been collecting desert sites data from many sensors. These data are gathered in an ORACLE database: for the moment, the available data are:

SeaWiFS, AVHRR (NOAA14,15,16)
MODIS, MISR
POLDER 1, SPOT 1,2,3,4, VGT,

The desert sites can be used in the following ways:

- To compare the absolute calibration of AATSR with the calibration of MERIS and other sensors
- To check the stability of the instrument calibration as a function on time.

10.1.2.3 Geographic Locations

The desert sites are given in Table 10.1.2.3-1.

Site Name	Lat centre (°)	Long centre (°)	Lat_min	Lat_max	Long_min	Long_max
Arabia1	18.88	46.76	18.38	19.38	46.26	47.26
Arabia2	20.13	50.96	19.63	20.63	50.46	51.46
Arabia3	28.92	43.73	28.42	29.42	43.23	44.23
Sudan1	21.74	28.22	21.24	22.24	27.72	28.72
Niger1	19.67	9.81	19.17	20.17	9.31	10.31
Niger2	21.37	10.59	20.87	21.87	10.09	11.09
Niger3	21.57	7.96	21.07	22.07	7.46	8.46
Egypt1	27.12	26.1	26.62	27.62	25.6	26.6
Libya1	24.42	13.35	23.92	24.92	12.85	13.85
Libya2	25.05	20.48	24.55	25.55	19.98	20.98
Libya3	23.15	23.1	22.65	23.65	22.6	23.6
Libya4	28.55	23.39	28.05	29.05	22.89	23.89
Algeria1	23.8	-0.4	23.3	24.3	-0.9	0.1
Algeria2	26.09	-1.38	25.59	26.59	-1.88	-0.88
Algeria3	30.32	7.66	29.82	30.82	7.16	8.16
Algeria4	30.04	5.59	29.54	30.54	5.09	6.09
Algeria5	31.02	2.23	30.52	31.52	1.73	2.73
Mali1	19.12	-4.85	18.62	19.62	-5.35	-4.35
Mauritania1	19.4	-9.3	18.9	19.9	-9.8	-8.8
Mauritania2	20.85	-8.78	20.35	21.35	-9.28	-8.28

Table 10.1.2.3-1 Desert Sites used for vicarious validation by Hagolle (119)

10.1.2.4 Validation Activities

10.1.2.4.1 Up to Validation Workshop

Up to the Validation Workshop, a limited comparison was carried out between AATSR and POLDER data over desert sites. The results were presented were preliminary and further work will be carried out in Phase E.

10.1.2.4.2 Validation in Phase E

Validation will continue in Phase E on a best efforts basis.

10.1.2.5 Data Requirements

Systematic use of every AATSR Level 1b ATS_TOA_1P product acquired over these sites

The default method of obtaining AATSR data for this work will be via the ENVISAT USF. PERL scripts provided by the USF will be used to set up a standing order for 512x512 km scenes over each site and to regularly download these products. The extraction of the suitable calibration points from the AATSR products will be performed manually by CNES.

Under AO 410, RAL will also be requesting data over certain desert sites and performing a similar extraction of relevant pixels (see Section 10.1.1). For those sites, which coincide between the two projects, there will be an exchange of MERIS and AATSR extractions between RAL and CNES.

10.1.3 Intercomparison of AATSR with MERIS and SCIAMACHY, Stammes (548)

The work outlined in AO 548 is primarily concerned with the validation of SCIAMACHY Level 2 products, namely, polarization, radiances, cloud and aerosols. It also, however, involves the use of MERIS and AATSR data for inter-comparison with SCIAMACHY data, and is included here for completeness. A more detailed description of the work can be found in the SCIAMACHY validation handbook (AD9).

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10.1.3.1 Methodology

The SCIAMACHY instrument measures the Earth's radiance between 240-1750nm, 1940-2040nm and 2265-2380nm. The spectral resolution is wavelength dependent, varying between 0.2 and 1.5nm. The measurements are performed in an alternating limb nadir mode such that an atmospheric volume is first observed in limb, and after 435 seconds, observed in nadir view. Solar and lunar occultation measurements are performed when possible. For radiometric calibration, an internal white light source can be observed as well as the sun and the moon. The default swath width of SCIAMACHY is 960km.

This work will compare normalised radiances of SCIAMACHY acquired in nadir mode to those of AATSR and MERIS. The normalised radiance is proportional to the ratio of the Earth's reflected radiance to the solar irradiance perpendicular to the solar beam. To this end, the AATSR and MERIS pixels will be collocated with the SCIAMACHY ground pixel, and averaged over the SCIAMACHY ground pixel. The SCIAMACHY normalised radiances will be convoluted with the instrument response functions of AATSR and MERIS. For the comparison, a partly cloudy scene over the ocean will be used, such that a large dynamic range is covered. The inhomogeneity of the scene allows confirmation of the positioning and geolocation of the instruments. A similar approach was successfully applied to GOME and ATSR-2 data (Koelemeijer *et al.*, 1998).

To assess SCIAMACHY degradation during its lifetime, SCIAMACHY normalised radiances acquired over a number of Saharan sites will be analysed (in conjunction with Hagolle, AO 119).

A second objective of this activity is cloud validation. The SCIAMACHY level 2 cloud products will consist of cloud cover fraction, cloud optical thickness, and cloud top pressure.

These cloud properties will be compared to cloud properties derived from MERIS and AATSR data. Cloud top pressure retrieval from SCIAMACHY employs the oxygen A-band, i.e. similar as MERIS. AATSR cloud top pressures will be derived by converting cloud top temperatures to pressures using atmospheric temperature profiles from the European Centre for Medium-range Weather Forecasts (ECMWF) model. A similar comparison was performed regarding effective cloud fractions and cloud top pressures derived from GOME and ATSR-2 [Koelemeijer and Stammes, 1999; Koelemeijer *et al*., 2000].

10.1.3.2 Geographic Location

Sites cannot be predefined.

10.1.3.3 Validation Activities

10.1.3.3.1 Up to Validation Workshop

No AATSR validation was carried out in the period up to the validation workshop, due to calibration problems with the SCIAMACHY sensor.

10.1.3.3.2 In Phase E

All the AATSR validation work described above will take place during Phase E.

10.1.3.4 Data Requirements

The team will receive half orbit ATS_TOA_1P on request, and 512 x 512 scenes of ATS_TOA_1P over desert sites.

The data should be sent to P. Stammes, address as above.

10.1.3.5 References

Koelemeijer, R.B.A., Stammes, P., and Watts, P.D., 1998, Comparison of visible calibrations of GOME and ATSR-2, *Remote Sensing Environment,* 63, pp 279-288

Koelemeijer, R.B.A., and Stammes, P., 1999, Validation of global ozone monitoring experiment cloud parameters using oxygen A-band measurements from the Global Ozone Monitoring Experiment, *J.Geophy.Res.,* 104, 18, pp 801-814

Koelemeijer, R.B.A., Stammes, P., Hovemnier, J.W., and de Haah, J.F., 2000, A fast method for retrieval of cloud parameters using oxygen A-band measurements from the Global Ozone Monitoring Experiment, in press.

10.1.4 MERIS/AATSR calibration using Arctic Stratus and Tropical CumuloNimbus clouds, Watts (501)

Philip Watts of RAL will provide calibration of the reflectance channels of the AATSR and MERIS instruments using cloud targets. Two methods and corresponding cloud types are utilised in conjunction with a multiple scattering plane parallel cloud model and NWP data to aid definition of atmospheric conditions.

This work is funded by ESA as an activity for MERIS, and hence calibration of the MERIS instrument is the main priority. Calibration of AATSR reflectance channels will also take place however. The work is described in AD8 (the MERIS Cal/Val implementation plan). The work is funded for launch + 1 year.

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10.1.4.1 Methodology

Two methods of calibrating AATSR data are used.

In the first method, Arctic stratus clouds are used to absolutely calibrate 0.55, 0.67 and 0.87 AATSR channels, using a comparison of nadir and along track reflectances and knowledge of the bi-directional reflectance distribution function.

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

For both methods, the following analysis steps are needed:

a) Selection of suitable target areas within the imagery

For the arctic stratus method, a suitable target is one that conforms closely to the plane-parallel model, is water cloud, contains a range of optical depths around $\tau = 4$, overlies blue water ocean and does not include strong sunlight geometry. These requirements are identified through both automated and non-automated methods.

For tropical deep convection, a suitable target is optically thick and geometrically deep, covers a large area, is illuminated at high solar angles, and lies over the ocean. Again automated and non-automated methods are used.

b) Prediction of the expected reflectance ratios (along track/nadir in stratus case, channel to channel in the tropical Cb case)

For both methods, expected reflectance ratios are calculated using a fast cloud-atmosphere-surface radiative transfer model developed for cloud parameter inversion as part of a study for SEVIRI.

c) Generation of calibration factors by comparison to measured ratios, and quality control of analysis fit.

10.1.4.2 Geographic Location

Using clouds as calibration targets mean that is hard to specify data over a specific geographic area. The presence and location of clouds is highly variable. To achieve a reasonable number of targets in a given time period, a large area must be defined.

The MERIS Calibration plan details a strategy for defining the geographic location needed. In summary, the single best search region for the arctic stratus clouds is the North Atlantic/North Norway region. For tropical deep convection clouds, the most useful areas are the Western Pacific and the Eastern Indian Ocean, with the convection moving seasonally with the inter-tropical convergence zone.

10.1.4.3 Validation Activities

10.1.4.3.1 Up to Validation Workshop

10.1.4.3.2 During Phase E

10.1.4.4 Data Requirements

- The following AATSR data products are required: ATS_TOA_1P.
- AATSR and MERIS data over cloudy scenes are required. Brockmann Consult will regularly screen full MERIS child data for suitable targets. BC will then send the selected data to Watts, deleting the other data that are not required. Corresponding AATSR data will have to be ordered by the AO team from the AATSR coordinators (HT and MCE).

10.1.4.5 Interfaces

Under contract to ESA, the MERIS team coordinator administers this activity. Monthly reports and results sent to the MERIS team coordinator will also be copied to the AATSR VS. Brockmann Consult will make pre-selection of scenes.

10.2 Specific Campaigns and the collection of ground measurements

In addition to the validation of the visible and near-infrared channels using vicarious methods, these channels can also be validated over land using dedicated field campaigns and the collection of ground measurements.

10.2.1 Ground data collection in Australia, Prata (9025)

Fred Prata of CSIRO has been undertaking radiometric measurements over land for a number of years, at three sites in Australia – Thangoo, Amburla and Hay. These three sites represent different environmental conditions and land cover types. Continuing work with ATSR and ATSR-2, ground measurements taken at sites in Australia will be compared with data from AATSR. Prata is named as a co-investigator on the proposal by Smith (410), and will work in collaboration with him. He is also involved in validation of the land surface temperature product (Section 11).

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Co-Investigators: Dr David Smith, RAL.

10.2.1.1 Instrumentation

A number of instruments will be used including ground-based spectrometers, sun photometers, radiosonde equipment and aircraft mounted spectrometers.

10.2.1.2 Methodology

Validation conducted by Prata will take the form of specific campaigns and long term monitoring. The validation methodology will be similar to that used for the ATSR-2 Atmospheric Correction Experiment (ACEX). The surface measurements and atmospheric data collected at the satellite overpass time were fed into a radiative transfer code (MODTRAN 3B) and TOA reflectances calculated for comparison with the ATSR-2 reflectances. The accuracy of this method of validation was limited by the spatial sampling of the ground-based reflectances. During the AATSR validation, the sampling problem will be overcome by the use of spectrometers flown aboard aircraft.

The first validation campaign will take place shortly after ENVISAT launch during the AATSR commissioning phase. The exact timing of the campaign will depend on selection of optimum weather conditions. Within 6 months, a second campaign will take place to establish the reproducibility of the validation results and to check on the stability and performance of the AATSR onboard calibration system. It is likely that these campaigns will take place at the Hay site, but consideration will be given to conducting the campaigns at Amburla.

The Amburla site is well suited to validation because of its homogeneity, stability and because it is an instrumented site. The most important aspect of validation at this site will be the ability to determine the site's spectral reflectance stability. For this purpose upwelling spectral irradiances should be monitored at the site. Overflights of the site using a video camera system approximately once per month are desirable. The spectral BRDF of the site should be measured at least once, from the air if funding permits, during the monitoring period.

10.2.1.3 Geographical Location

Validation work will be carried out at three locations in Australia – Uardry, Amburla and Thangoo. These are summarised in Table 10.2.1.3-1.

Field Site	Longitude (E)	Latitude (S)	Height (m)	Climate	Surface type
Uardry	145.304	-34.392	110	Temperate	Grassland
Amburla	133.119	-23.385	626	Semi-arid	Bare Soil
Thangoo	122.352	-18.179	60	Tropical	Savanna

Table 10.2.1.3-1 List of the 3 Australian sites, their locations and character

The sites are all instrumented differently. They are all within 200km of a radiosonde site and measure the upward and downward components of the short-wave and long-wave radiation field. Some sites have optical depth measurements.

- Uardy

Hay plains, New South Wales, Australia
Uardry is a semi-arid grasslands site located on the vast Hay plains some 50 kilometres east of the township of Hay. The site and surrounding region are dry land grazing properties (mainly sheep) characterised by large treeless expanses of natural vegetation located on extremely flat and homogeneous natural terrain. The overlying atmosphere is characterised by a semi-arid climate with low amounts of water vapour and aerosols. Regular winter/spring rainfall provide seasonal vegetative growth. The site has moderate column amounts of water vapour (typically 10 to 30 kg m^{-1}) and aerosol optical depth (typically 0.03 at 0.5 micron). Instruments monitor continuously at several points the surface radiation budget components (broadband shortwave and longwave fluxes, downwelling and upwelling), meteorological parameters, and in clear daytime skies the aerosol optical depth, column ozone and water vapour amounts.

- Amburla

Tanami Desert, Northern Territory, Australia
Amburla is an arid desert site located on a long flat plain (approximately 30 km x 12 km) characterised by a red soil with a sparse cover of Mitchell grass. The site, which is located 100 kilometres northwest of Alice Springs, is used for cattle and camel grazing. Ephemeral vegetative growth following heavy tropical thunderstorm activity or slow-moving rainband activity, may be significant but is uncommon. The site has moderate column amounts of water vapour (typically 5 to 40 kg m^{-1}) and aerosol optical depth (typically 0.03 at 0.5 micron). The site is instrumented to continuously monitor at several points the surface radiation budget components (broadband shortwave and longwave fluxes, downwelling and upwelling) and meteorological parameters.

- Thangoo

Thangoo is uniform over an area of at least 3 km x 3 km and characterised by a hot and humid monsoonal summer climate, a warm to hot and relatively dry winter climate, and significant aerosol loading in spring and early summer due to large uncontrolled bushfires. A location at the southern extent of the ITCZ (inter- tropical convergence zone) is planned to minimise monsoonal activity (cloud) and maximise the summer day-to-day atmospheric variability (aerosol and water vapour). Continuous monitoring at several points will include the surface radiation budget components (broadband shortwave and longwave fluxes, downwelling and upwelling), meteorological parameters, and in clear daytime skies, the aerosol optical depth, column ozone and water vapour amounts.

10.2.1.4 Planned Validation Activities

Measurements are being undertaken at the three validation sites on a continuous basis. During the commissioning phase, validation reports will be made available on a monthly basis. It is hoped that dedicated campaigns will be undertaken to complement the continuous measurements.

10.2.1.5 Data Requirements

- The following AATSR data products are required:
  ATS_TOA_1P
- Transfer of products via ftp.
- The data needed are offline.

Address to where data should be sent:

Dr Fred Prata
Address as above.

11 Land Surface Temperature Prototype Product

The L2 GST product, currently produced by the ENVISAT payload data segment, does not contain a Land Surface Temperature retrieval. It has a placeholder for such a value over land but at the current time, this field contains the 11 µm brightness temperature over land.

CSIRO have proposed an AATSR LST retrieval, and during the ENVISAT Commissioning Phase, this retrieval is to be tested in the AATSR Prototype Processor. Following an initial evaluation of the prototype retrieval, a decision will be taken whether or not to add the retrieval to the Operational Processor used in the ENVISAT payload data segment.

RAL, under contract to ESA, will be responsible for implementing the algorithm within the PP, with assistance from CSIRO. It is hoped that the prototype product will be available at Launch, or by the end of the AATSR SODAP at L+2 months at the latest.

CSIRO will be responsible for providing an initial assessment of the algorithm's performance, over Australian sites. Other experts working in this field have been invited to review the results of the algorithm and contribute validation results to increase the number of geographical areas covered by this initial evaluation. Fred Prata (as lead scientist for AATSR LST retrieval) and Marianne Edwards (as AATSR Validation Scientist) will jointly co-ordinate the activities of this group, and will be responsible for reporting results back to ESA and DEFRA at the ENVISAT Validation Workshop at L+9 months.

It should be noted that at present, there will be no spatially averaged LST retrieval. This will be considered once the retrieval in the 1 km product has been optimised.

Members of the land surface validation team are:

- Fred Prata, CSIRO
- Jose Sobrino, University of Valencia
- Simon Hook, JPL
- Julienne Stroeve, University of Colorado
- Cesar Coll, University of Valencia

Data requirements and distribution

During the commissioning phase, the prototype LST product will be produced at RAL and distributed to team members via an ftp server. The exact mechanism for this data dissemination is TBD.

Interfaces

The AATSR VS will coordinate the LST validation team in conjunction with Dr Fred Prata. Team members will receive data from RAL, and send validation results back to the VS. The VS will then laise with Dr Prata.

Schedule

All team members will follow the schedule given in Section 14.

11.1 Land Surface Temperature validation projects

11.1.1 LST product validation over sites in Australia

Dr Fred Prata, the author of the LST ATBD will conduct LST product validation over sites in the Australia (the same sites as used for validation of the visible and near infrared wavelengths, as discussed in Section 10.2.1).

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11.1.1.1 Methodology

The details described here are taken from:
Prata, A, 2000 The proposed global land surface temperature product for Envisat's AATSR: Scientific basis, algorithm description and validation protocol, in Proceedings of the ERS-Envisat Symposium 'Looking down to Earth in the New Millennium' Gotherburg 16-20th October 2001.

The ideal method for obtaining an independent validation dataset is to use two multi-channel radiometers with AATSR pass-bands from an aircraft and from the ground. The measurements should be made as close as possible to the overpass time of AATSR and ancillary data relating to atmospheric profiles and emissivity measurements must be collected. The target validation site must be uniform at scales of hundreds of meters to several kilometres. The sky must be clear during the measurement period and the aerosol content of the atmosphere must be low.

Given that it is unlikely that this ideal measurement protocol will be met on many occasions, 3 alternative strategies will be used:
i. Gathering large amounts of less accurate near-simultaneous temperature measurements at well chosen sites.
ii. Using numerical model temperature simulations from high resolution mesoscale models.
iii. Comparison of the AATSR LST product with MODIS, AVHRR and GLI LST products.

The first strategy has been implemented using the Australian validation sites shown in Table 10.2.1.3-1. The data from these sites consist of contact temperature measurements and radiometric measurements. The contact temperatures are representative of satellite measurements although biases exist under certain atmospheric and surface conditions. The radiometer data also show a strong correlation with the satellite data, but these measurements must be emissivity corrected prior to comparison with the AATSR LST product.

Currently there are 3 radiometers operating at the Thangoo site, 4 at Uardry and 1 at Amburla. The validation data set will consist of:
- 30 minute time-series of 2 minute temperature averages and standard deviations, centred on the time of the overpass. The temperatures will consist of spatially averaged contact measurements over an area of approximately 1 * 1 km^2. The number of sensors used in the spatial average will vary.

- 30 minute time series of radiometer measurements (average and standard deviations). Appropriate for the nadir and forward views of AATSR.
- Radiosonde profiles of temperature and moisture made at the nearest upper-air station to the site.
- 30 minute time series of upward and downward longwave and shortwave flux density measurements.
- 30 minute time series of aerosol optical depths at 0.55, 0.67 and 0.87 μm obtained from multi-filter rotating shadowband radiometers.
- Library spectral emissivity profile measurements made at each site. Only one dataset per site it envisaged, but this may be expanded to several seasonal datasets as resources permit.
- Standard surface meteorological data (air temperature, wind-speed, humidity and surface pressure) at each site as 30-minute time-series centred on the overpass.

The dataset required for the mesoscale model will depend on the exact details of the model employed. A minimum dataset might comprise:

- Surface temperature. This must be as close to the surface as possible without being below the ground. The lowest vertical level in the atmosphere will not be appropriate. Inversion of the Stefan-Boltzmann flux density to get a radiative transfer temperature would be acceptable to use.
- Vertical profiles of temperature and moisture.
- Description of surface character
- Model estimate of degrees of cloudiness
- Description of model grid size, integration step size and vertical resolution

Comparisons with products from other satellites can only be done when the measurements are nearly simultaneous. The kind of information required for this validation include:

- 11 and 12 μm TOA brightness temperatures at the site.
- Pixel-by-pixel LST at a minimum of 5 x 5 pixels, centred on the pixel closest to the site.
- Pixel-by-pixel spectral emissivity retrievals (if available) at a minimum of 5 x 5 pixels, centred on the pixel closest to the site.
- Satellite data and time of acquisition of collocated pixel.
- Satellite view zenith and azimuth angles of collocated pixel for daytime data, sun zenith and azimuth angles.
- Satellite measure of cloudiness. This cloud be a cloud flag, a confidence flag or for daytime data reflectance, values in the shortwave channel of the sensor being used.
- Description of the theoretical basis for the LST product.

11.1.1.2 Geographical location

The geographical location of validation sites are given in Table 10.2.1.3-1.

11.1.1.3 Data Requirements

The AATSR LST prototype product over selected sites.

In addition to AATS LST product data over the 3 Australian sites, data over other sites will also be needed for quality control and global validation. Key areas for global validation include:

1. Snow and ice covered surfaces

2. Boreal forest
3. Tropical forest
4. Mid-latitude agricultural land
5. Desert
6. Mixed, close-canopy forest
7. Steppe

Approximately 40 clear-sky AATSR data products (20 ascending, 20 descending) from these regions and the Australian sites are required. Table 11.4.1.3-1 gives details of the geographic locations of the sites chosen.

Area	Description	Longitude	Latitude
		+ = E, - = W	+ = N, - = S
1	Greenland	-40	+74
2	Canada	-105	+54
3	Borneo	+113	-1.5
4	Spain	-1	+39
5	Sahara	0	+30
6	Siberia	+114	+68
7	Kamchatka	+158	+56

Table 11.4.1.3-1 AATSR product requirements for global quality control

11.1.2 LST product validation over the Barrax test site

Land surface temperature validation will be carried out using the Barrax test site. This is a 100 km^2 agricultural area in the Albacete county (Castilla La Manche), which has been used for many national and international studies. The main crops in the area are wheat, barley, corn and alfafa.

Principal Investigator Dr José A.Sobrino
Department of Thermodynamics,
Faculty of Physics
University of Valencia
Dr. Moliner, 50
46100, Burjassot
Spain

11.1.2.1 Methodology

1. A series of temperature measurements are taken of the surface using a CIMEL radiometer, to obtain radiometric temperature of the surface (Tr). This has wavebands in the 11 and 12 µm wavelengths.
2. Surface emissivity is derived though a series of emissivity transects using the box method (ϵ).
3. Using the CIMEL radiometer, effective atmospheric temperature is derived (Ta).
4. Using Tr, ϵ and Ta, the in situ Land surface temperature is obtained. This is then compared to the LST obtained from AATSR using the proposed algorithms

Measurements can be made at the site throughout the year.

11.1.2.2 Geographical Location

Validation will be done at the Barrax test site, located at 39° 03’ N, 2° 05’W. This is an agricultural site, 28km from the city of Albacete. The site is defined by the coordinates:

39° 01' N, -2° 05' W
39° 07' N, -2° 05' W
39° 03' N, -2° 00' W
39° 03' N, -2° 11' W

11.1.2.3 Data Requirements

- The AATSR LST prototype product.

11.1.2.4 References

Sobrino, J.A., Reillo, S., Cuenca, J., and Prata, A.J., Surface temperature from ATSR-2 data: Algorithms and validation. ERS-ENVISAT Symposium, Gothenburg, 16-20th October 2000

Sobrino, J.A., Soria, G, and Prata, A.J., Surface Temperature from ATSR-2 data: Algorithms and Validation. Journal of Geophysical Research (submitted)

11.1.3 LST product validation over the Greenland ice sheet

Land surface temperature validation will be carried out around the Greenland ice sheet.

Principal Investigator: Dr Julienne Stroeve
CIRES, Campus Box 449
University of Colorado
Boulder
CO 80309-0449
Email: stroeve@kodiak.colorado.edu

11.1.3.1 Methodology

Automatic weather stations are situated around the Greenland Ice Sheet. These collect a number of data including:

- Air temperature
- Wind speed
- Wind direction
- Humidity
- Pressure accumulation rate at high temporal resolution to identify individual storms
- Surface radiation balance in visible and infrared wavelengths
- Sensible and latent heat fluxes
- Snow pack conductive heat fluxes

Hourly average data are transmitted via a satellite link (GOES or ARGOS) to the University of Colorado throughout the year. In addition, measurements are stored in solid state memory. The system is powered with two 100 Ah batteries, charged by a 10 or 20 W solar panel. The satellite data-link is powered by two separate 100 Ah batteries connected to a 20 W solar panel. This set-up guarantees continuous data recordings and storage, even in the case of satellite transmission failure. The expected lifetime of the instrumentation is 5 years.

Data at some sites have been available since 1992 and data collection continues. In 2001, three more stations were installed in the ablation region of the ice sheet. At these sites, skin temperature is not measured. However, profiles of air temperature and temperature in the snow pack may provide the opportunity to derive the skin temperature. Alternatively, net solar radiation and net radiation information together with modelled incoming longwave radiation could be used to estimate the surface temperature. This may however, lead to large errors though since the errors for the individual instruments could translate into large errors in the outgoing LW radiation at the surface.

Figure 11.4.3.1-1 shows one of the Greenland AWS.

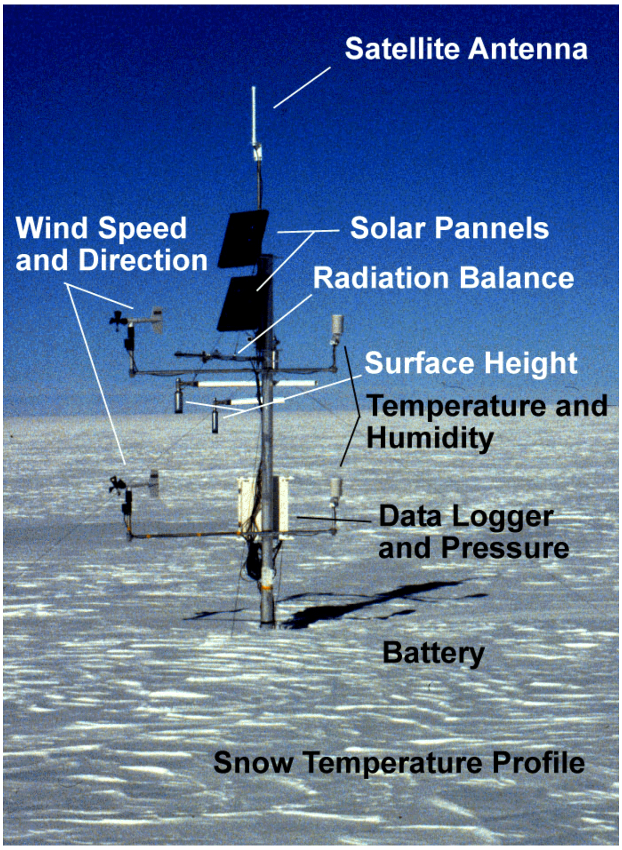

Figure 11.4.3.1-1 Automatic Weather Station situated in Greenland
(Source of Photo: http://cires.colorado.edu/steffen/gc-net/gc-net.html)

11.1.3.2 Geographical Location

Figure 11.4.3.2-1 shows the location of automatic weather stations over Greenland. The location in Lat/Long is provided in Table 11.4.3.2-1.

	Latitude	Longitude		Latitude	Longitude
1	69.57317	49.29517	10	66.00055	44.50139
2	69.8819	46.97358	11	63.14889	44.81667
3	73.8333	49.49528	12	75	29.99972
4	77.1433	61.095	13	69.91333	46.85472
5	78.5266	56.8305	14	75.09975	42.33256
6	72.57944	38.50417	15	66.47944	42.50027
7	78.01677	33.99387	16	69.69942	33.00058
8	66.48096	46.27995	17	69.417	50.124
9	69.49835	49.68156	18	65.75845	39.60177

Table 11.4.3.2-1: Location of the automatic weather stations in Greenland

11.1.3.3 Data Requirements

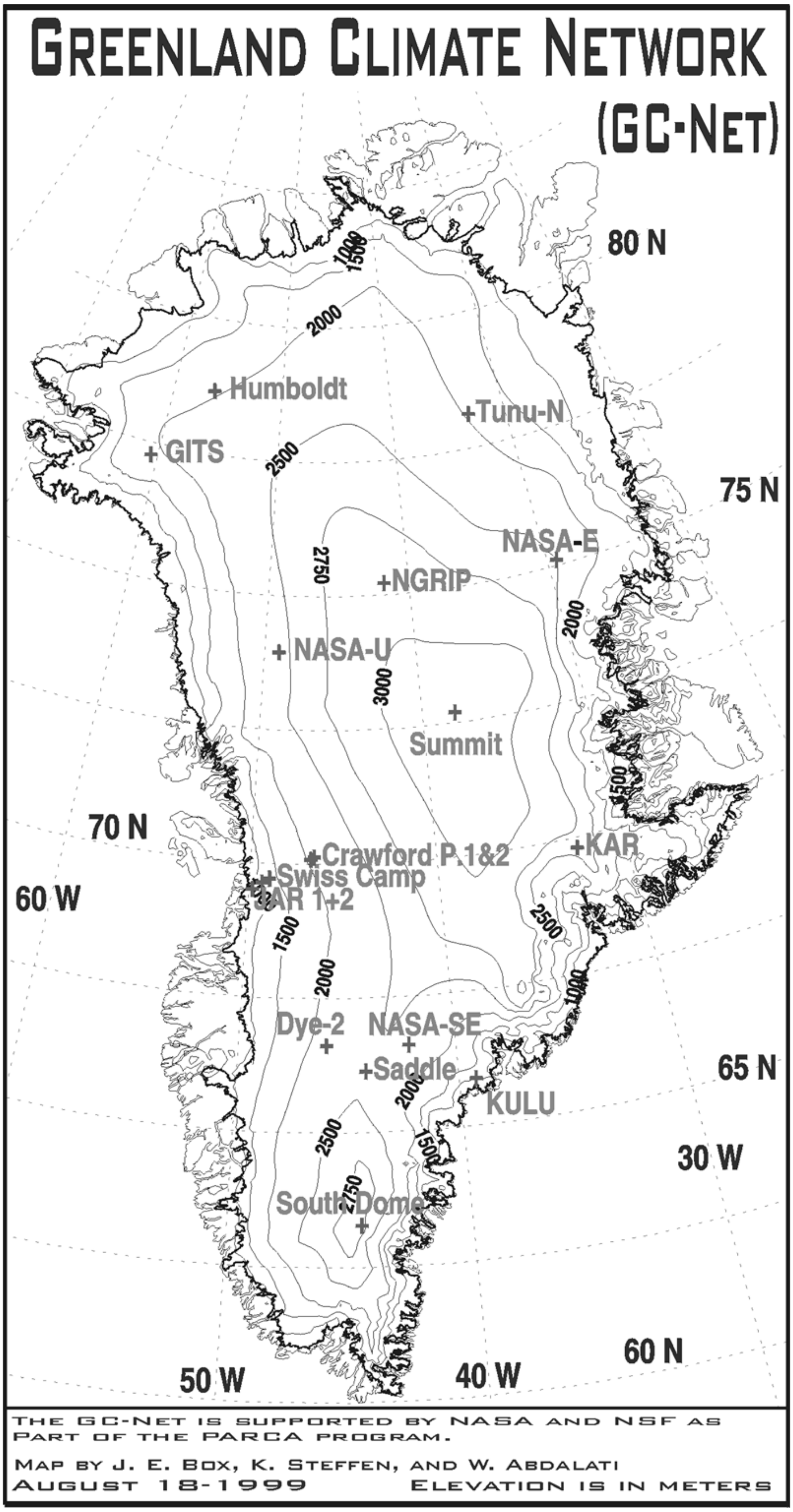

Figure 11.4.3.2-1: Location of Automatic Weather Stations over Greenland
(Source of Image: http://cires.colorado.edu/steffen/gc-net/gc-net.html)

11.1.4 LST product validation in Valencia

Dr Cesar Coll will carry out LST validation at a site near Valencia.

Principal Investigator: Dr Cesar Coll
Dept. of thermodynamics, Faculty of Physics
University of Valencia
Dr Moliner, 50
46100-Burjassot (Valencia)
Spain

11.1.4.1 Methodology

The validation site is within a large area of rice fields, located a few kilometres south of Valencia City. The area is completely flat and surrounds the Albufera Lagoon. The size of the area is 3 km * 3km. The most ideal time for validation is June to September when the rice crops have full growth and attain nearly full cover. Daily visits can be made to the field site depending on weather conditions and staff availability.

Temperatures will be measured using two Everest and one CIMEL (4 bands) radiometers, along prefixed transects covering one square of 1km by 1km. Measurements will be made ±1 hour around AATSR overpass time. Measurements will include:

- Radiometric temperatures at selected points along transects, and time of measurement.
- Atmospheric downwelling radiances.
- Emissivity of plants and underlying soil (CIMEL bands at 11 and 12 μm).
- Air temperature and humidity at surface level.
- Local radiosonde measurements for one or two days. The Spanish meteorological office launches radiosondes at 00 and 12 hr. The nearest measurements are Palma de Mallorca, Barcelona and Murcia.

11.1.4.2 Geographical Location

Figure 11.4.4.2-1 shows a false colour ASTER image of the study area (taken June 30th 2000). The study area appears red in the bottom right of the image around the lagoon.

Figure 11.4.4.2-1 ASTER image of the Valencia study area (30th June 2000)

The coordinates of the study area are:

0° 21’ 40 W

39° 22’ 40 N

11.1.5 LST product validation at Lake Tahoe

Dr Simon Hook will carry out LST product validation at Lake Tahoe, a large lake situated in a granite graben near the crest of the Sierra Nevada Mountains on the California - Nevada border

Principal Investigator: Dr Simon Hook
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109
(818) 354-4321

11.1.5.1 Instrumentation

In order to validate mid (3-5 μm) and thermal infrared (8-14 μm) data from airborne and spaceborne instruments in-flight, the Jet Propulsion Laboratory (JPL) and University of California at Davis (UCD) are currently maintaining four surface sampling stations on Lake Tahoe (Hook et al. 1999, 2000, 2001). The four stations are referred to as TR1, TR2, TR3 and TR4 (Figure 11.1.5.1-1). Each raft/buoy has a custom-built self-calibrating radiometer and several temperature loggers. The sensor end of each of the loggers is mounted ~2 cm beneath the surface on a floating support that trails behind each raft (Figure 11.1.5.1-2). The radiometers are near-nulling and self calibrating. They are accurate to ± 0.1 K. NIST traceability is provided by laboratory calibration of the radiometer against the JPL cone blackbody that was traced to NIST using their transfer radiometer. The temperature loggers are calibrated in a NIST-traceable water bath. Each raft contains a data logger with dial-up cellular telephone access. The data logger receives data from the radiometer and 4 temperature sensors mounted on the support trailing each raft. The data are automatically downloaded daily via cellular telephone modem to JPL allowing near real-time monitoring. The other static temperature loggers are included for redundancy and downloaded approximately every two months under normal operations. A full set of measurements is made every 2 minutes. However, the units can be remotely re-programmed if a different sampling interval is desired. Meteorological stations (wind speed, wind direction, relative humidity, air temperature and net radiation) are also included on TR1, TR3 and TR4 (Figure 11.4.5.1-2). A similar meteorological station will be added to TR2 in the near future.

Both JPL and UCD maintain additional equipment at the US Coast Guard station that provides atmospheric information (Figures 11.1.5.1-1 and 11.1.5.1-3). This includes a full meteorological station (wind speed, wind direction, relative humidity), full radiation station (long and shortwave radiation up and down), a shadow band radiometer and an all sky camera. The shadow band radiometer provides information on total water vapour and aerosol optical depth.

Measurements of algal growth rate using 14C, nutrients (N, P), chlorophyll, phytoplankton, zooplankton, light, temperature and secchi disk transparency are also made tri-monthly at the Index station and monthly samples for all constituents except algal growth and light are made at the Mid-lake station. Many samples are taken annually around the Tahoe Basin to examine stream chemistry and snow and atmospheric deposition constituents.

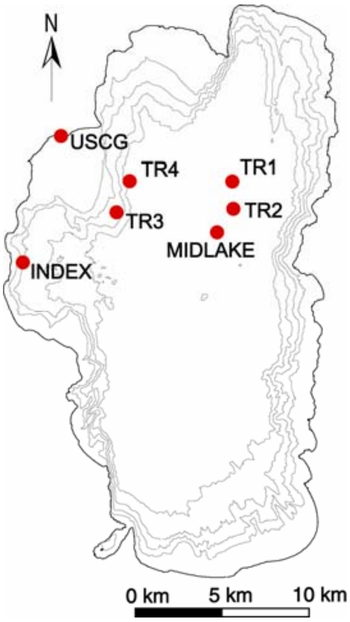

Figure 11.1.5.1-1. Bathymetric map of Lake Tahoe with a contour interval of 100 m. The 4 NASA rafts are labelled TR1, TR2, TR3 and TR4. Also shown is the US Coast Guard station (USCG), Midlake and Index stations. A variety of atmospheric measurements are made at the USCG and a variety of water properties are measured at the Midlake and Index stations.

Figure 11.1.5.1-2. Surface monitoring station at TR1. The station measures the radiometric skin temperature, bulk temperature, wind direction (magnetic) and speed, relative humidity, air temperature and net radiation.

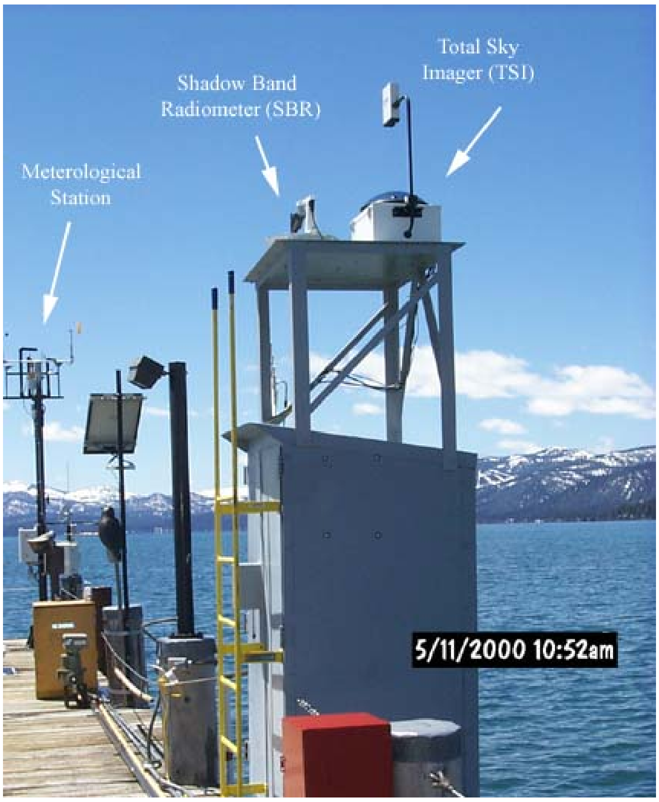

Figure 11.1.5.1-3. Yankee Total Sky Imager (TSI) and Yankee Multi Filter Rotating Shadowband Radiometer (MFRSR) located above the gauging station on the US Coast Guard Pier. A full meteorological station is also located on the pier and maintained by UCD.

11.1.5.2 Methodology

The strategy adopted to validate the mid and thermal infrared data and products from airborne and spaceborne instruments was to first validate the radiance at sensor data and then validate the derived surface products (radiance, temperature, emissivity). In the AATSR study, the radiance at sensor product will be validated followed by the land surface temperature product. A key feature of the Lake Tahoe validation site is that measurements are made continuously. This allows us to validate all clear overpasses provided suitable tools exist for extracting the infrared data.

Radiance at Sensor Product – ATS_TOA_1P GBTR

The procedure for validating the radiance at sensor product is summarized as the follows:

- Obtain the interpolated NCEP atmospheric profile for the time of the overpass.
- Correct the surface radiometric measurements to surface skin temperature.
- Calculate the average bulk temperature for each raft.
- Calculate the skin effect (difference between the average bulk and skin temperature).
- Determine the skin temperature for rafts with bulk temperature values only.
- Propagate the surface skin temperature to at-sensor radiance using the radiative transfer model (MODTRAN 3.5) driven by the atmospheric profile.
- Convolve the modelled at-sensor radiance with the system response functions for the satellite radiometer.

- Extract the satellite radiometer at-sensor radiance values over each of the rafts. For AATSR a 3x3 km area (3x3 pixels) will be extracted. The area extracted is centred on the location of each raft, which was determined by differential GPS.
- Calculate the average difference between the predicted and satellite measured values.
- Assess the accuracy of product over time.

Step (1) – Obtain the interpolated NCEP atmospheric profile for the time of the overpass

Atmospheric profiles are obtained from the National Centre for Environmental Prediction (NCEP). The NCEP produces global model values on a 1-degree by 1-degree grid at 6 hr intervals. Lake Tahoe is centred on 39 N, 120 W and the grid value for this point is utilized. The NCEP data are interpolated to the overpass time.

Step (2) – Correct the surface radiometric measurements to surface skin temperature

The radiometers measure the radiative temperature of the skin of the lake over the 7.8-13.6 µm wavelength region and in order to obtain the skin (kinetic) temperature it is necessary to correct the data for any atmospheric and emissivity effects. The skin temperature is derived by correcting for surface emissivity and subtracting the sky radiance reflected by the surface into the path of the radiometer:

$$L_{obs} = \int_{\lambda} R(\lambda)\left[L_{path}(\lambda) + \tau(\lambda)\varepsilon(\lambda)L_{BB}(T,\lambda) + \tau(\lambda)(1-\varepsilon(\lambda))\frac{I_{sky}(\lambda)}{\pi} \right] d\lambda \qquad \text{Equation 1}$$

Where:

$L_{obs} = observed\ radiance\ at\ sensor$

$L_{BB} = blackbody\ radiance\ (Planck\ \ function)$

$L_{path} = emitted\ radiance\ \ from\ surface - sensor\ \ path$

$I_{sky} = total\ downwelling\ irradiance\ upon\ the\ surface$

$\lambda = wavelength$

$T = temperature$

$\tau = surface - sensor\ \ path\ tranmit\tan ce$

$\varepsilon = surface\ \ emissivity$

$R = Normalized\ \ system\ spectral\ response\ \ function$

The path transmittance, path radiance, and downwelling irradiance terms are obtained from a radiative transfer model (MODTRAN 3.5) driven by a supplied atmospheric profile obtained in Step (1). The emissivity of the water was obtained from the ASTER spectral library. The emissivity of water has been shown to change with view angle and wind speed. Currently these affects are not accounted for, however, modelled values of the emissivity variation of water with wind speed and view angle were obtained recently and will be incorporated into future analyses. With all terms of Equation 1 determined, the equation is solved for temperature by iteration. It should be noted the path transmittance terms and path radiance terms are for the 1m of air between the water surface and the radiometer. For a high altitude site with a dry atmosphere these terms are close to 1 and 0 respectively.

Step (3) Calculate the average bulk temperature for each raft

The bulk temperature is measured approximately 2 cm beneath the surface by several different types of temperature sensors. Initially, the temperature trace of each logger over time is examined to make sure the logger is reading correctly. This is necessary because the cables from the loggers occasionally develop leaks causing the temperature values to drift. The data from any suspect loggers are discarded and the two temperature values closest to the overpass time, for a given logger, are linearly interpolated to the acquisition time of the nadir pixel. The mean and standard deviation of the interpolated values for each raft is then calculated. Since the measurements are normally made every 2 minutes with a maximum of every 5 minutes the interpolation time is typically less than 2 minutes.

Step (4) Calculate the skin effect

The skin effect is calculated as the bulk temperature minus the skin temperature. The skin effect is typically less during the day than at night. The smaller skin effect observed in the daytime is attributed primarily to strong solar heating coupled with low wind speeds. However, other factors are important such as the difference between the air and water temperature. Figure 11.1.5.1-4 shows a plot of some recent field data acquired over Lake Tahoe at the TR3 station on June 7th 2001. These data were derived using the Mk III near-nulling radiometer and include simultaneous meteorological data. These data are from a calm day; notice that as the solar elevation increases (1600 GMT, 0800 PST), the bulk and skin temperature both increase, with the skin temperature increasing more rapidly and surpassing the bulk temperature until the early afternoon. In the early afternoon the wind increases, resulting in a reduction in the skin and bulk temperatures (shown by a double arrow on Figure 11.1.5.1- 4). The morning increase in the bulk temperatures is also associated with an increase in the standard deviation of the bulk temperature measurements (not shown). The standard deviation of the bulk temperatures also decreases in the early afternoon as the wind increases due to greater mixing. In the late afternoon the wind speed decreases and a skin/bulk differential is established which remains fairly constant throughout the night. As the wind speed increases in the early afternoon, so does the air temperature as warm air from the adjacent land is blown over the lake. Days characterized by low wind speeds and strong solar heating occur predominantly in the spring and fall. These data illustrate the importance of measuring the skin (what the satellite measures) rather than bulk temperature which could be different by as much as ± 0.5 K.

Step (5) Determine the skin temperature for rafts with bulk temperature values only

In some cases, the radiometric temperature is not available at a given overpass or for a particular raft on a given overpass. If no radiometric temperatures are available from any of the rafts, the radiometric temperature is estimated by adding the average difference for all the overpasses to the bulk temperature at each raft. If radiometric temperatures are available at some of the rafts then the average difference of the available radiometric temperatures is calculated and added to the bulk temperatures of the rafts that have bulk measurements but no radiometric measurements to estimate the radiometric temperature at that raft.

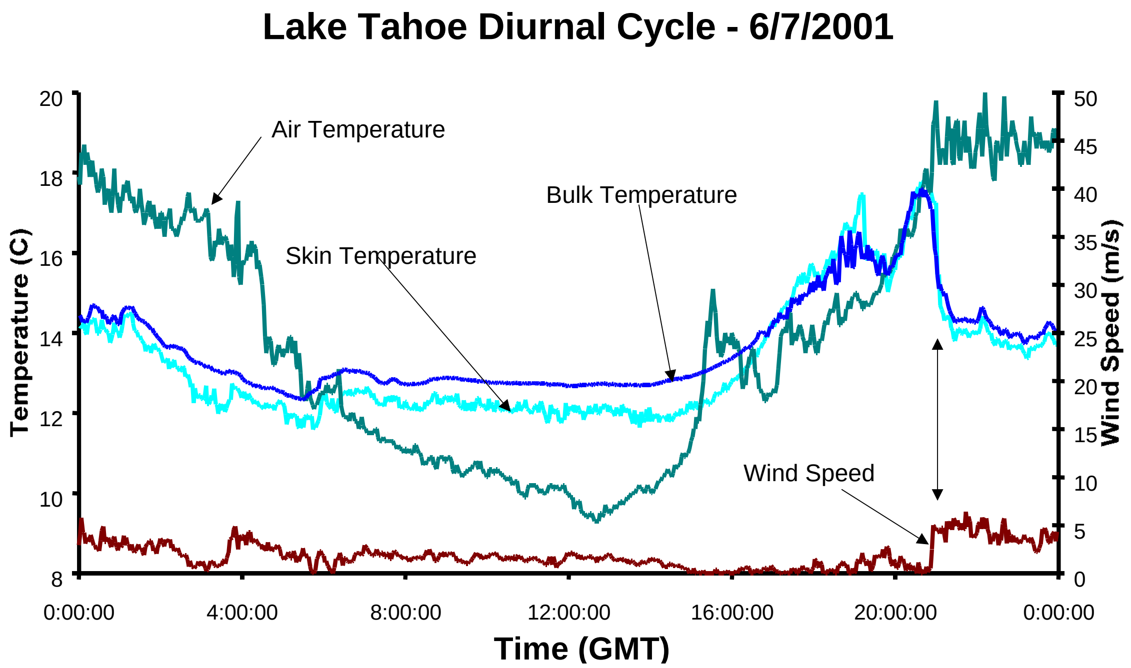

Figure 11.1.5.1-4. Variations in the bulk-, skin-, air-temperatures and wind speed on June 7, 2001 at L. Tahoe.

Step (6) Propagate the surface skin temperature to at-sensor radiance

The at-sensor radiance is calculated using a radiative transfer code (MODTRAN 3.5) driven by the interpolated NCEP profile obtained in Step (1) and the derived surface skin temperature and emissivity of water.

Step (7) Convolve the modeled at-sensor radiance with the system response functions for the satellite radiometer

The high-resolution at-sensor radiance spectrum obtained in Step (6) is convolved to the sensor system response. This step necessitates that the AATSR project provide the sensor system response for the AATSR channels.

Step (8) Extract the satellite radiometer at-sensor radiance values over each of the rafts

For AATSR data a 3x3 km area (3x3 pixels) will be extracted. The area extracted is centred on the location of each raft, which has been determined by differential GPS

Step (9) Calculate the average difference between the predicted and satellite measured values

For each overpass day there are typically 4 validation points (1 per raft). For each of these points the difference between the predicted (derived from ground measurement) and the satellite-measured values is calculated. These 4 values are then averaged to obtain an average difference between the predicted and measured values for a given overpass day.

Step (10) Assess the accuracy of product over time

This involves determining the average uncertainty between the measured and predicted radiances over time.

Land Surface Temperature Prototype Product: Temperature

The procedure for validating the surface temperature product is summarized as:

- Obtain the interpolated NCEP atmospheric profile for the time of the overpass.
- Correct the surface radiometric measurements to surface skin temperature.
- Calculate the average bulk temperature for each raft.
- Calculate the skin effect (difference between the average bulk and skin temperature).
- Determine the skin temperature for rafts with bulk temperature values only
- Extract the satellite derived surface temperature values over each of the rafts. For the AATSR data a 3x3 km area (3x3 pixels) will be extracted. The area extracted is centred on the location of each raft, which was determined by differential GPS.
- Calculate the average difference between the predicted (derived from satellite) and ground measured values. Note the predicted values are now those derived from the satellite.
- Assess the accuracy of product over time.

A detailed description of these steps is provided in the validation procedure for the at-sensor radiance product, where appropriate.

Land Surface Temperature Prototype Product: Emissivity

The procedure for validating the surface emissivity product is summarized as:

- Extract the satellite derived surface emissivity values over each of the rafts. For the AATSR data a 3x3 km area (3x3 pixels) will be extracted. The area extracted was centered on the location of each raft, which was determined by differential GPS.
- Convolve a laboratory spectrum of emissivity to the system response function of the instrument. For water the emissivity spectrum is well known when nadir-viewed.
- Calculate the average difference between the predicted (derived from satellite) and ground measured values. Note the predicted values are now those derived from the satellite.
- Assess the accuracy of product over time.

11.1.5.3 Geographic Location

Lake Tahoe is a large lake centered on 39 N 120 W on the California-Nevada border. The level of Lake Tahoe is approximately 1898 m above MSL. It is roughly oval in shape with a N-S major axis (33 km long, 18 km wide), and has a surface area of 500 km^2 (Figure 11.1.5.1-1). The land portion of the watershed has an area of 800 km^2. Lake Tahoe is considered a deep lake; it is the 11th deepest lake in the world, with an average depth of 330 m, maximum depth of 499 m, and a total volume of 156 km^3. The surface layer of Lake Tahoe deepens during the fall and winter. Complete vertical mixing only occurs every few years. Due to its large thermal mass, Lake Tahoe does not freeze in winter. There are approximately 63 streams flowing into the lake and only one river flowing out of the lake. Lake Tahoe is renowned for its high water clarity. However, the water clarity has been steadily declining from a maximum secchi depth of 35 m in the sixties to its current value of ~20 m. Research by UC Davis (Jassby et al. 1999; Paerl et al. 1975) has identified that the decline is in part due to increased algal growth facilitated by an increase in the amount of nitrogen and phosphorus entering the lake and, in part, due to accumulation of small suspended inorganic particulates derived from accelerated basin-wide erosion and atmospheric inputs.

11.1.5.4 Planned validation Activities

Measurements at the Tahoe site are made every 2 minutes on a continuous basis. In addition there are periodic validation campaigns when supplemental measurements are made, e.g. aircraft data. It is assumed no additional coordination will be required for these campaigns since the equipment is "always on" and AATSR data will always be acquired over the site.

11.1.5.5 Data requirements

- The following AATSR data products are required:
  ATS_TOA_1P
  Land Surface Temperature Prototype Product
- Data volume: 512 x 512 scenes of ATS_TOA_1P and Land Surface Temperature Prototype Product for every overpass over the site (day AND night).
- Data needed are offline.

Address to where data should be sent

Dr Simon J. Hook
Mail Stop 183-501
Jet Propulsion Laboratory
Pasadena, CA, USA 91109

References

http://shookweb.jpl.nasa.gov/validation
http://modis-land.gsfc.nasa.gov/val/
http://blt.wr.usgs.gov/

Hook, S. J., Prata, A. R. and S. G. Schladow, 1999. Interim Status Report. Available from: http://eospso.gsfc.nasa.gov/validation/terraval.html.

Hook, S. J., Prata, A. R. and S. G. Schladow, 2000. Interim Status Report. Available from: http://eospso.gsfc.nasa.gov/validation/terraval.html.

Hook, S. J., Prata, A. R. and S. G. Schladow, 2001. Interim Status Report. Available from: http://eospso.gsfc.nasa.gov/validation/terraval.html.

Jassby, A. D., Goldman, C. R., Reuter, J. E. and R. C. Richards, 1999. Origins and scale dependance of temporal variability in the transparency of Lake Tahoe, California-Nevada. *Limnology and Oceanography*, vol. 44, pp. 282-294.

Paerl, H. W., Richards, R. C., Leonard, R. L. and C. R. Goldman, 1975. Seasonal nitrate cycling as evidence for complete vertical mixing in Lake Tahoe, California-Nevada. *Limnology and Oceanography*, vol. 20, pp. 1-8.

12 Summary of validation activities during the initial validation phase

Sections 9 to 11 outline the different validation activities that were scheduled to take place during the commissioning phase of Envisat. These are summarised in Table 12-1 in relation to validation of the different products.

Product ID	Name	Description	Validation	PI
ATS_NL__0P	Level 0 Product	• Instrument source packet data	No	
ATS_TOA_1P	GBTR	• Full resolution top of atmosphere BT/reflectance for all channels and both views.	0.55µm, 0.67 µm, 0.87 µm and 1.6 µm over land and cloud	Smith Hagolle Stammes Watts Prata
			3.7µm, 11µm, 12µm – inherent through validation of SST level 2 products, and LST product	
		• Product quality data, geolocation data, solar angles and visible calibration coefficients	Specific validation through algorithm verification activity. Inherently validated though validation of other products	Birks
ATS_NR__2P	GST	• Full resolution nadir-only and dual-view SST over sea	Yes	Robinson/Donlon Barton Minnett Nightingale
		• Full resolution 11 µm BT and Normalised Difference Vegetation Index (NDVI) over land	NDVI not validated Prototype LST product to replace 11µm BT	Prata Sobrino Stroeve Coll Hook
		• Product quality data, geolocation data and solar angles	Specific validation through algorithm verification activity. Inherently validated through validation of other products	Birks
ATS_AR__2P	AST	• Spatially averaged ocean, land and cloud parameters	Yes	Robinson/Donlon Barton Minnett Nightingale
		• Spatially averaged top of atmosphere BT/reflectance	Inherently validated through validation of other products.	
ATS_MET_2P	Meteo Product	• SST and averaged BT for all clear sea pixels, 10 arc min cell, for Meteo users	Yes	UK Met Office
ATS_AST_BP	Browse Product	• 3 band colour composite browse image derived from L1b product. 4 km x 4 km sampling.	Not officially validated, but the product will be examined, and the LUT reviewed as part of the algorithm verification work.	Birks

Table 5-1: Validation of AATSR data products

Figure 12.1 shows the validation activities that took place.

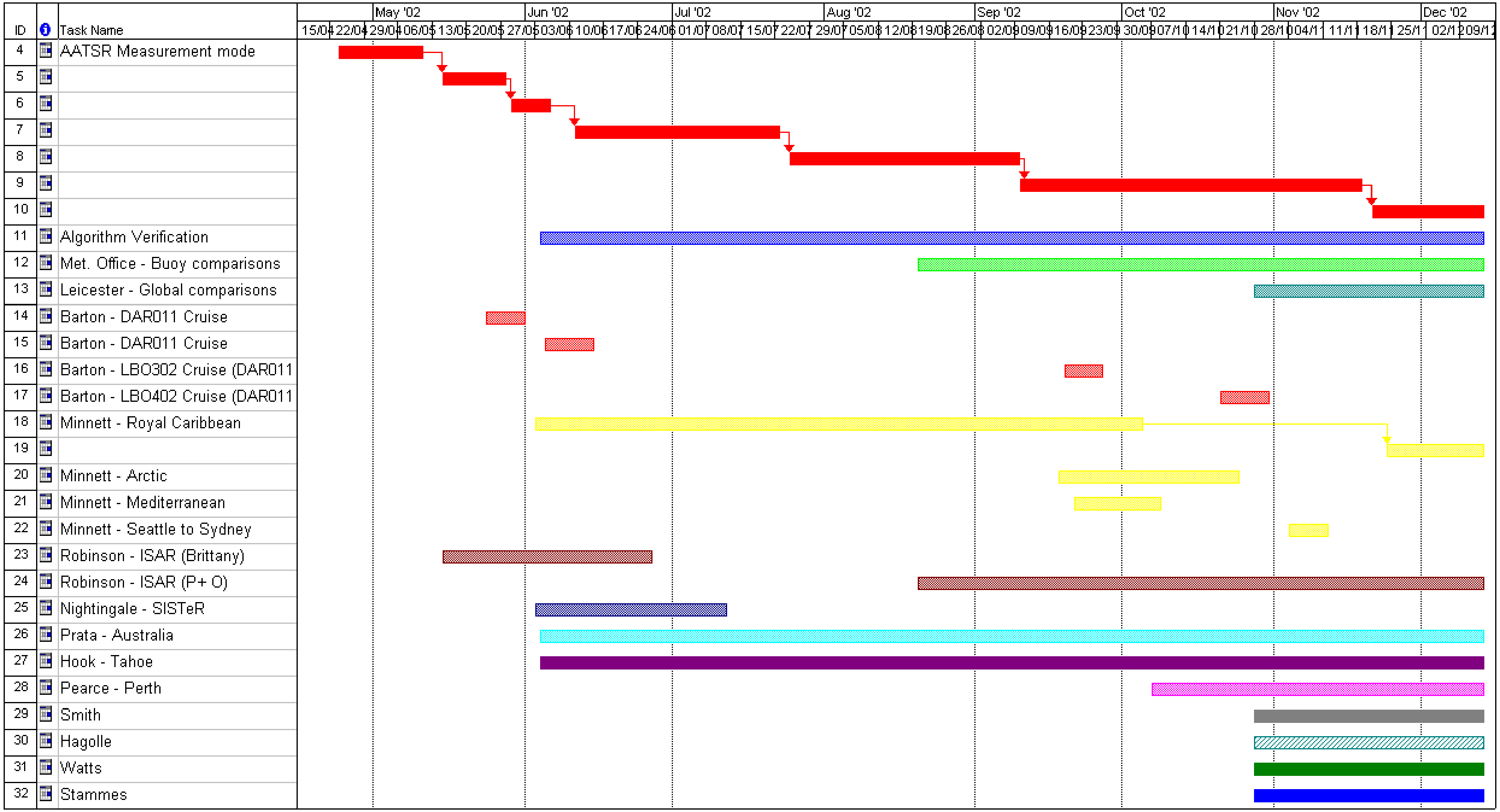

Figure 12.1-1 Validation activities during the first nine months of the Envisat mission

In summary, there have been 8 dedicated validation cruises and 6 instruments running autonomously.

- Algorithm verification has been underway since data delivery to Andrew Birks at RAL in June 2002. Ideally, algorithm verification would have been completed before the start of validation. However due to the timetable adopted, these activities proceeded in parallel.
- The Met Office started receiving near-real-time AATSR data on the 19th August 2002. They have been comparing the AATSR METEO product with buoy data and SST analysis fields almost continuously since that time. There have been small breaks due to the unavailability of the METEO product to the Met Office.
- The University of Leicester have been comparing AATSR ASST data with SST data from other sensors since the start of L2 data distribution to Leicester at the end of October 2002.
- I. Barton (CSIRO) has deployed the DAR011 precision radiometer on 4 dedicated validation cruises. The 13 validation points he has been able to collect on these cruises, in only a few months, is a major achievement.
- P. Minnett (RSMAS, Uni. of Miami) has three MAERI radiometers. One of these has been deployed almost continuously on a ship in the Caribbean. The University of Leicester is analysing the data collected, and converting and uploading data files to the NILU database. To date, 184 files have been uploaded. The other MAERI instruments have been deployed on 3 cruises of opportunity, in the Arctic, the Mediterranean and from Seattle to Sydney. Unfortunately the last cruise had to be abandoned due to bad weather, but from the other deployments, a significant number of validation points have been collected.
- The ISAR radiometer has been deployed by the University of Southampton on two ferries, the Val de Loire and the Pride of Bilboa. The first deployment from May 15th to June 26th was much more successful than the second deployment which has suffered from technical difficulties and poor weather.
- Funded through a NERC Enabling Grant, T. Nightingale deployed SISTeR on a cruise in the Indian Ocean, obtaining 4 ATSR-2/AATSR validation points from a possible 17.
- The vicarious validation work of Smith, Hagolle, Watts and Stammes started when data distribution to the AATSR PI's started at the end of October.

13 AATSR Data Requirements and Distribution

13.1 Data Requirements

In order to ascertain satellite data requirements during the commissioning phase, and the logistics of data distribution and circulation, Hannah Tait (ESA ESTEC) has compiled a spreadsheet of validation data requirements. This spreadsheet is primarily to aid ESA in planning, and is constantly evolving and changing as plans develop and requirements change. A copy of the spreadsheet can be obtained directly from Hannah Tait, and she should be notified of any additions or modifications to the current estimates.

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13.2 Data Distribution

Full details of AATSR data distribution to Envisat Cal/Val PI's during the commissioning phase can be found in the technical note PO-TN-ESA-GS-1227, written by Hannah Tait (HT). To summarise:

- In general, ca/val PI's will have access to AATSR data from L + 3 months, after the instrument SODAP and one month of algorithm verification. Earlier access will be considered on a case-by-case basis.

- NRT products will be generated from unconsolidated Level 0 data, within 3 hours of acquisition. Off-line products will be generated 2-3 weeks after acquisition. All AATSR cal/val PI's (with the exception of the UKMO using the Meteo product) will be provided with off-line products during the commissioning phase.

- Level 1b data (ATS_TOA_1P product): 512 * 512 scenes
  During the commissioning phase, level 1b data will be ordered via AATSR coordinators (HT and ME). There will be no systematic distribution.
  Data requests for PI's with long-term pre-defined site locations (a fixed buoy or field site monitored over months or years) will be pre-programmed into the PDS before launch by ESA, for systematic delivery whenever an overpass crosses the site.
  Short term requirements and/or requirements over sites yet to be determined will be entered into the USF on an as-needed basis by HT. PI's should inform HT of their requirements.
  Level 1b data will be available in 512 x 512 km scenes, to download from the UK-PAC by FTP. PI's are responsible for downloading data from the FTP site. Overpass data used to generate the order will be supplied in order to identify the product for download (orbit number and start/stop time will be in the product filename).
  PI's validating SST are expected to use mostly L2 data, with L1b only used for anomaly investigations. If PI's are generating their own SST data from L1b data, the 'official' SST coefficients, as used by ESA should be used.

- Level 2 data (ATS_NR_2P and ATSR_AR_2P)

Level 2 data will be generated at the UK-PAC.
The 14 orbits of off-line L2 data generated each day will be written onto CD. This master CD will be copied and routinely distributed to a mailing list of users once per day, every day. PI's will therefore receive 3 CD's a day throughout the commissioning phase. ESA will help PI's identify the correct orbit number of the data they require from the CD, with information being provided in the form of overpass tables. Alternatively, ESOV can be used. The orbit number of a product will appear in the product name. One product represents one whole orbit. Once extracted, the product can be read into EnviView. A tool (PdsPixels) will be provided with EnviView to aid PI's in extracting the pixels of interest.

- The Meteo product

The Meteo product will be available to the UKMO from L + 3 onwards.
It can be ftp'ed from Kiruna within 3 hours, available in both PDS and BUFR format.
The 4 blind orbits are available within one day.

- Special cases:

AO 501: Watts et al
This AO requires AATSR and MERIS data over cloudy scenes. Brockmann Consult will regularly screen full MERIS child data for suitable targets. BC will then send the selected data to Watts, deleting the other data that are not required. Corresponding AATSR data will have to be ordered by the AO team from the AATSR coordinators (HT and MCE).

AO 552: Robinson/Donlon
This AO requires RA-2 data. This will be sent to Donlon on CD.

AO 410/119: Smith/Hagolle
These AO's use the same sites, for MERIS and AATSR. The MERIS data will be extracted by the METRICS tool, running on the IECF.

14 Schedule for validation activities

Figure 14-1 shows the validation activities that will take place in Phase E, up to the end of 2003. In summary: -

- The UK Met Office will continue to validate the AATSR METEO product throughout the period.
- The University of Leicester will continue to carry out global comparisons of AATSR SST with data from other sensors until July 2003. After that work is TBD.
- I. Barton has two validation cruises planned for the DAR011, in the Gulf of Carpentaria and out of Darwin. In addition there may be other 'piggy-back' validation cruises not yet defined (TBD).
- One of the MAERI instruments will continue to operate on the Royal Caribbean Cruise Liner. Data collection is funded by NASA although data analysis and validation is performed by the University of Leicester in collaboration with P. Minnett, and hence funded by DEFRA. This activity will continue given the availability of funding. The other two MAERI instruments will be deployed on cruises in the Mediterranean, Canadian Arctic, from Sydney to Seattle and from Australia to Japan.
- The ISAR instrument will continue to be deployed on the Pride of Bilboa given the availability of funding. ISAR may also be deployed on another ship, the Falstaff, operating between the United States and Europe (TBD).
- F. Prata and S. Hook will continue to deploy autonomous instrument on sites in Australia and Lake Tahoe respectively.
- CSIRO autonomous instruments will operate on passenger ferries from Perth and Townsville.
- The long term monitoring of desert sites by D. Smith will continue throughout the period (funding TBC). Long term monitoring by O. Hagolle will also continue on a best efforts basis.
- The AATSR validation activities of Watts and Stammes are of a finite length and expect to be completed mid-2003.
- Nieke carrying out validation activities mainly for MERIS but also for AATSR, has a field campaign planned in the Arctic for April 2003. Further campaigns beyond this one are TBC.

It is envisaged that initial validation activities will end in mid 2003, marked with an AATSR validation workshop (TBC).

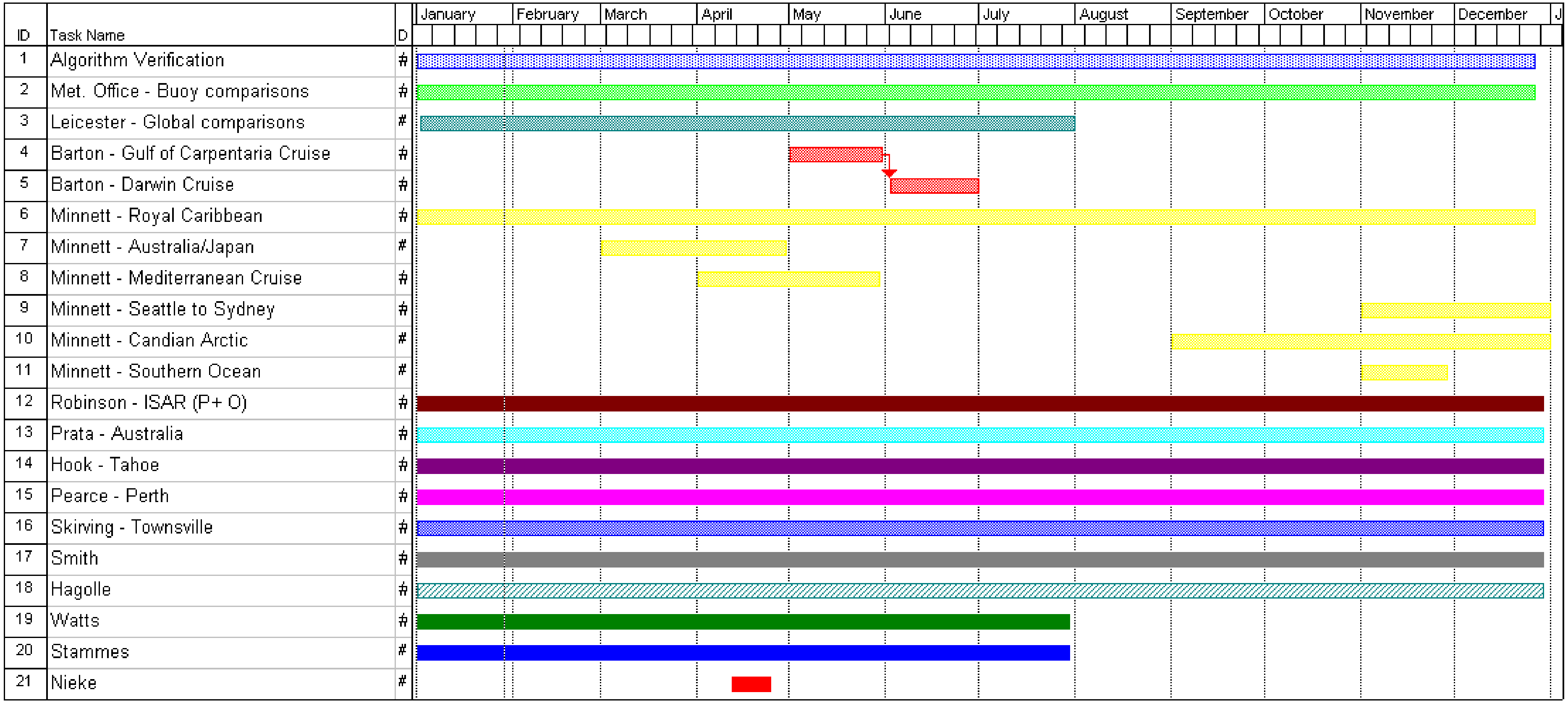


Figure 14-1 AATSR Validation activities scheduled for Phase E

The Validation Loop

During the commissioning phase, and up until the validation workshop at L + 9 months, it is important that validation results are reported and acted on, quickly and effectively. The validation loop in Figure 15-1 has been produced to illustrate the mechanism by which this will occur[4]. It describes what happens to the validation data once collected.

1. Following ENVISAT Launch, and the AATSR Switch On and Data Acquisition Phase (SODAP), AATSR data will become available to AATSR validation data providers (VDP's). VDP's will inform the Validation Scientist (VS) of any planned campaigns, and the VS will ensure that the Flight Operations Support team are aware of these campaigns in their planning. This will ensure that the data will be collected at that time, if this is possible, or that the VDP is informed in advance of the non-availability of the instrument. VDP's will order and receive AATSR data, collect in situ measurements and perform in situ/satellite matchups. VDP's will submit validation data to the NILU database.

2. Following the SODAP, for the remainder of the Commissioning Phase, once a month, VDP's will send the VS information files containing the in situ/satellite matchups plus any analysis/comments they have. If validation data are unavailable on a monthly basis, the VDP's will still send a short report detailing progress, and expectation of the timing of results (see Section 15-1).

3. During commissioning, ESA will perform algorithm verification, and will report results to the VS. The VS will report results of the algorithm verification to the VDP's.

4. The VS will coordinate validation activities, collating all the results received, and analysing them. If the validation data reveal anomalies and errors, the VS will investigate possible sources of error, by asking VDP's to check their data, and seeking advice from the PP team, the FOS team and the PDS team. If thought necessary, investigations by the various specialist teams may take place at this stage on a limited scale. In this way, a basic level of quality assurance will be applied.

5. The VS will produce monthly validation reports, which will be sent to members of the DQG. The DQG will be an ad hoc group, convened by the VS as required (i.e. whenever there is a significant input of validation results). It will communicate via email and meet as necessary, as part of an FOS or AATSR SAG meeting, or as an AATSR validation team meeting. Depending on the validation report under review, a meeting of the DQG will involve appropriate people – namely the PI, the Project Scientist, the VS and the FOS manager, and validation PI's as necessary. DEFRA, ESA, and NERC will have full visibility of the group and can attend meetings, if desired.

6. The DQG will review the validation results, and decide what, if any, further action is needed. They may authorise further investigations (into the validation data collected, the data processing chain, the instrument etc). The VS will coordinate any further investigations, and report back to the DQG.

7. If a change to the data processing is recommended by the DQG, this change will first be tested with the PP. If results of the test confirm that a change in the operational

[4] 25/03/02 Following the re-organisation of review groups by DEFRA, the validation loop is currently under review.

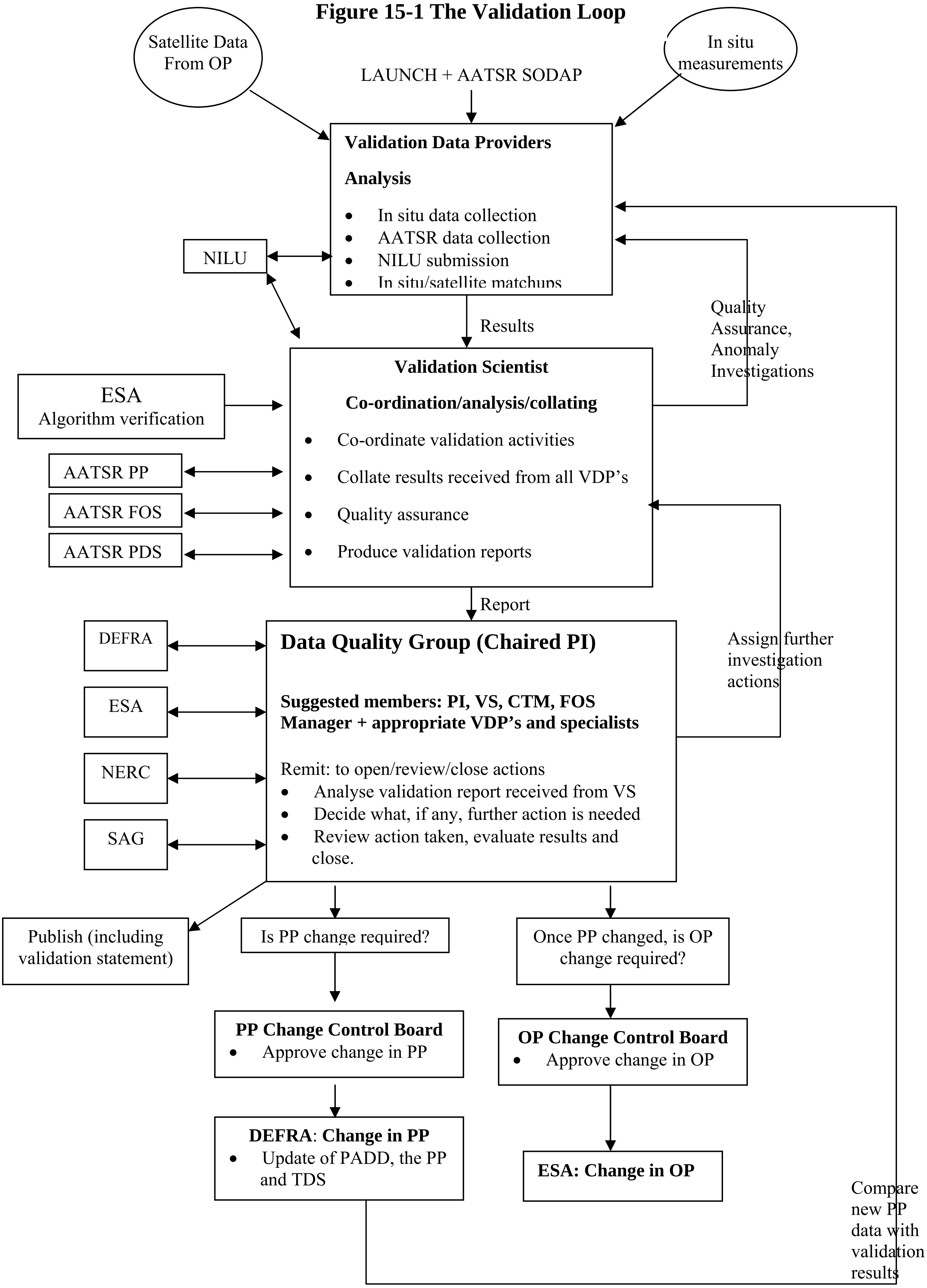
system is needed, recommendations to permanently change the PP are passed to DEFRA. A Change Control Board (ESA, DEFRA, PI, SAG) meets to approve the change. If a change is approved, DEFRA updates the PADD, the PP and the TDS. New data from the PP are provided to the VDP's, and tested against validation results.

8. Following successful testing, a change in the OP is made, and the validation loop begins again.

9. Statements about the status of validation activities will be made by the DQG on a regular basis and published on the AATSR validation website.

10. Following the commissioning phase, the validation loop will continue, although it is envisaged that meetings of the DQG will be held less frequently.

Figure 15-1 The Validation Loop



14.1 Reporting

As described in the validation loop, VDP's will report to the VS on a monthly basis. Provisional dates for these reports are given in Figure 14.1. In order to minimise paperwork and ease interpretation of reports, a reporting template will be provided for VDP's, made available in word and pdf form on the AATSR validation website (http://www.leos.le.ac.uk/aatsr). In addition to monthly reporting, VDP's are encouraged to use this form to report anomaly or result information at any other time. The form should be returned to the VS.

A longer reporting template will be provided for reporting results for the commissioning phase review and validation workshop. For these two events, longer reports giving more detail are required.

Having received and collated reports, the VS will report to appropriate parties as shown in the validation loop. VDP's will be kept informed of progress and results through monthly emails and the AATSR validation website. It is hoped that validation results can be discussed within the team using the discussion forum on the website.

In addition, VDP's are expected to submit correlative data to the NILU database, following the metadata guidelines provided by NILU.

15 Future Validation Activities

As described in Section 4, the objectives of the AATSR validation programme are extended post-commissioning to include:

- Validate AATSR SST products in an increasing number of sites and seasons.
- Monitor long-term data product quality.
- Validate new products.

Many of the activities detailed as initial validation activities will continue, whilst additional activities will be conducted by the wider scientific community.

Continuation of Commissioning Phase Activities

Table 17.1-1 gives an indication of the continuation of commissioning phase activities after the validation workshop at L + 9 months. Year 2 and 3 represents one and two years from L + 9 months respectively.

ID No.	Activity	Post-commissioning
9084	Global buoy comparison, including early indication of gross errors.	Continuation of activities throughout years 2 and 3.
9081/2	Robinson/Donlon: ISAR5C	Continuation of activities throughout years 2 and 3, pending availability of funding. Deployment of ISAR5C 1 and 2 in more geographic locations. (TBC)
9024	Barton: Rottnest Island Ferry, Perth	Continuation in years 2 and 3, pending availability of personnel and funding (TBC).
9024	Barton: Pure Pleasure Ferry, Townsville	Continuation in years 2 and 3, pending availability of personnel and funding (TBC).
590	Minnett: M-AERI	Continuation in years 2 and 3, pending availability of cruises and funding (TBC)
9024	Barton: DAR011	Continuation in years 2 and 3, pending availability of funding, cruises and berths (TBC)
410	Smith: Vicarious inter-calibration of AATSR and MERIS using terrestrial targets	Long term monitoring of desert sites, pending availability of funding. (TBC)
501	Watts	Activity continuing to L + 1 year
9025	Prata	Planned continuation of field data collection, pending availability of funding (TBC)

Table 17.1-1 Continuation of initial validation activities, post the validation workshop at L + 9 months.

Additional validation activities

Table 17.2-1 lists ESA A/O proposals that have been categorised as ‘Science’ proposals, and which include validation work. These PI’s will receive data when it is released for general use at the end of the commissioning phase. (NB Some listed projects use AATSR data, but only as a means of validating data from MERIS. Nevertheless, these may make interesting contributions and have been included here for completeness).

Validation Activity, AO Project No.	Parameter investigated (in relation to AATSR)
889 (Rao)	SST using in-situ ship and buoy data
656 (Kwarteng)	Atmospheric Aerosol
647 (Doerffer)	SST
247 (Matzler)	Surface Temperature, Atmospheric Parameters
595 (Parslow)	SST
861 (Fischer)	Cloud optical thickness, and cloud albedo
609 (Sorensen)	Atmospheric parameters
864 (North)	Aerosol Opacity and land surface bi-directional reflectance

Table 17.2-1: Additional post-commissioning validation projects, not included in the core validation programme

In addition to these AO science proposals, it is hoped that validation data will come from the wider scientific community. Initial contact has already been made with several groups with a view to future collaboration regarding validation work.

New Products

A number of new products are being discussed for AATSR data. If new products are developed, validation will be carried out post-commissioning to validate the parameters derived.

As described in Section 11, an AATSR land surface temperature product is being prototyped for inclusion in the L2 products. Following successful validation during the commissioning phase, a decision will be taken as to whether to make this product operational.

16 Development of the AATSR Validation Implementation Plan

The AATSR Validation Implementation Plan is a working document, and will continue to evolve throughout the mission. Versions 1 and 2 of the plan deal specifically with validation activities during the commissioning phase. It is envisaged towards the end of the commissioning phase, Version 3 will be issued providing more information on validation activities that will continue into Envisat Phase E, the Exploitation phase.